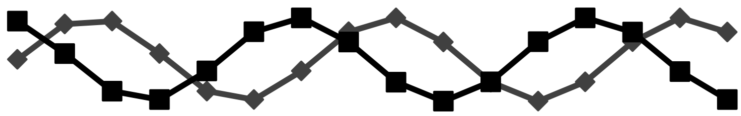
Jan Tinbergen's Move from Physics to Economics, 1922-1930



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Abstract

While Jan Tinbergen was one of the great economists of the 20th century, his early life has received little attention from historians. This is remarkable because Tinbergen was not an economist, but a physicist by training. Tinbergen had studied physics in Leiden under the wings of Paul Ehrenfest, and made the transition from physics to economists roughly between 1922 and 1930. This study argues that Tinbergen's transition should be understood in the context of his political beliefs, the changing position of the academic in the Dutch society and a pre-existing tradition of exchange between physics and economics. In addition to showing Tinbergen's motivation for becoming an economist, this study will also show how he used his physical background in his political and economic writings.

Preface

The completion of this thesis marks the end of a project that started on the 5th of September 2013. That day I sent an email to Jeroen van Dongen, asking him for a meeting to discuss some possible topics for my research thesis. I came into his office two weeks later with a list of ideas: something to do with rationality in science, I recall, and (knowing myself in that stage) probably also something to do with Quine. Jeroen listened patiently to what I had to say, gave a deep sigh, and responded:

"Tja, van dik hout zaagt men planken". ("Yeah, that's not specific enough")

Followed by:

"Maar wacht, deed jij niet iets met economie?" ("But wait, didn't you do something with economics?")

Since my background was in philosophy and economics, he had a better idea: to look into the economic writings of Paul Ehrenfest who, *by the way,* supervised Jan Tinbergen on his dissertation. I promised him I would think it over. As I walked out the door, I recalled thinking that I didn't know whether that was a good or a bad meeting. On the one hand, my own ideas were thrown out as soon as I finished explaining them. On the other hand, this new idea was pretty interesting. I had never even contemplated writing a historical thesis. And yet here I was…

…And there I went.

Now, roughly two years after, that project has come to an end. My topic, it will have become clear from the title, had meandered: from Ehrenfest (and a bit of Tinbergen) to their relationship, and onward to Tinbergen himself. At the same time I have, one could say, 'taken my time'. I assure the reader this was not out of laziness. In fact, my other occupations implied that my work on this project was often done in fragmented evenings, weekends and vacations. That is all on me, of course, and I hope my work hasn't suffered – and if it has, I am cautiously confident that I have repaired at least some of it.

As is so often the case with getting out of your comfort zone, I have learned some unexpected lessons from writing this thesis. As a newbie historian, I experienced for the first time the kind of silent admiration that you can feel for historical figures, when you feel like you are witnessing their conversations from afar. As a hobbyist politician, I have gotten more and more respect for a political school that is not my own. And as a philosopher-economist, I more and more learned the sense behind both Imre Lakatos' insistence that philosophy of science is blind without history (and history of science empty without philosophy) and John Maynard Keynes belief that the master-economist could not do without history philosophy. All this goes to say: I learned a lot.

I am grateful to the ever critical and patient Jeroen van Dongen. Much like the scene from the above, pretty much every meeting I had with him ended with me getting tangled up in a field of work that was completely foreign to me –history was a start, but then came thermodynamics, and then quantum mechanics. That's a sign of confidence (if not of hopeful overestimation) from his part, for which I am grateful. I should also thank Marcel Boumans, the man who *literally* wrote the book on Tinbergen and Ehrenfest. His enthusiasm for my project was a very welcome antidote to the exasperation I sometimes felt from the more technical stuff. I am greatly indebted to the Boerhaave Museum and Erfgoed Leiden for allowing me to look into the letters of Paul Ehrenfest in the midst of their digitalization. Similarly, I owe my thanks to Jan Jüngen of the Erasmus University Library, who went to great lengths in order to arrange my access to Jan Tinbergen's letters. Huub Brouwer continued his good habit of reading pretty much everything I write before it can do any damage, and his comments were helpful as ever. Roelof van Dijk double-checked my interpretation of the mathematics in Tinbergen's dissertation, though any remaining errors are of course my own.

As always, I am grateful to my friends and family supporting me, even when they don't know they do. I'll close with the same words as my other thesis – I hope this makes you proud.

Utrecht, 29th of November 2015

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1. Introduction

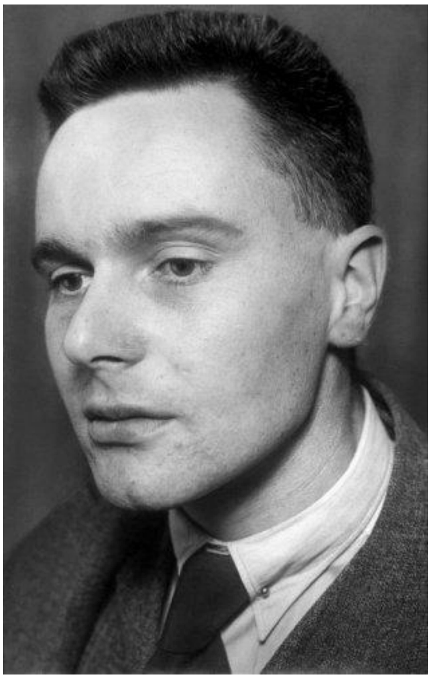
1.1. Of crystals, people and their relations

"One cannot of course not say that space, crystals and the planets are evidently "mathematical objects" while denying the same for people and their relations"[1]

In March of 1925, an article by the rather mysterious title 'Mathematics – Limit – Marx' appeared in Kentering ('Change'), the periodical of the Social Democratic Student Club (SDSC). The author of the article was a physicist who had barely turned 22 by the time of publication: Jan Tinbergen, born in The Hague on the 12th of April 1903 and one of the co-founders of the SDSC in 1924.

The article discussed whether the economy could benefit from a mathematical treatment. Many economists had argued that it could not: mathematics was accused of treating complicated matters too simply and without flexibility. Tinbergen disagreed. According to him, these criticisms followed from an incorrect view about the nature of mathematics. This view wrongly assumed that mathematics was limited to the kind most people had been taught: geometry and algebra. Treatments with these tools is straightforward: in geometry, one derives conclusions about shapes and angles from shapes that one can, generally, easily imagine and that are relatively simple – simple, at least, when compared to economic phenomena such as prices and production processes. Tools of this kind could never be usefully applied to economics, or so the argument goes.

According to Tinbergen, these views conflated mathematics with their domain of application. The simplicity of geometry does not follow from its mathematical nature, but from its domain of application: space. Because space is simple – or at least our conventional ideas about space, Tinbergen said in acknowledgement of relativity theory – so is its treatment with mathematical tools. The economy and our ideas about it are considerably more complicated than conventional intuitions about space. Ideas about the relations between lines at a particular angle and the sum of the angles in triangles and squares are replaced by a world in which a complex trifecta of consumers, producers and government interact with each other and the world. Yet Tinbergen believed that mathematics can still be of use, if we let go of our preconceptions about its simplicity. He mentions three virtues:



Jan Tinbergen around 1933

Figure 1

[1] "Men kan uiteraard niet zeggen dat ruimte, de kristallen of de planeten uiteraard "wiskundige" objecten zijn en de mensen en hun verhoudingen niet." (Kentering March 1925, p. 67, my translation)

1. Mathematics as an archive of logic.

As an 'archive of logic', mathematics allows the economist access to the fruits of other sciences. Tinbergen believed that solutions to problems in other disciplines might prove useful to economists, provided they conform to particular traits:

> "Mathematics contains, as it were, an extensive collection of problems solved, ready for use, which, whenever a scientific problem arises that possesses particular characteristics, is able to give an answer that would otherwise arise from a long and difficult process of reasoning (…) The value of the hypothesis is thereby irrelevant" (p. 66, my translation)

2. Mathematics as a shortcut to empirical facts.

As a shortcut to empirical facts, the use of mathematics allowed economists to summarize empirical data, e.g. about prices and unemployment, in the form of mathematical relations. These mathematical relations were much easier to handle than cumbersome tables, as he illustrates briefly by the example of Wicksell and Böhm-Bawerk.

3. Mathematics for the integration of theories.

In Tinbergen's words, "mathematical equations are much easier to *combine* than common argumentation" (p. 67). In verbal argumentation, it is often difficult to see how different arguments relate to each other. Two economic theories often don't rule each other out, but suggest different mechanisms that may reinforce each other of move in opposite directions. By representing these theories mathematically, theories that pertain to different factors can be integrated into a theory of the whole.

Tinbergen emphasized that these three uses of mathematics have long been known to physicists. Tinbergen had studied with and been the assistant of the renowned Austrian physicist Paul Ehrenfest since 1922, and had the privilege of meeting many of the great minds of the discipline at the regular symposia that Ehrenfest organized at his house in Leiden. For these reasons it is unsurprising that Tinbergen both justified and illustrated his faith in the mathematization of economics by referring to his academic 'home turf'.

This article, the second of many that Tinbergen would write for Kentering, was evidence of an agenda that Tinbergen would carry out throughout the rest of his life: his belief that mathematics and statistics could greatly benefit the economic discipline. As this article shows, and Boumans (1992) has argued, Tinbergen's innovative approach to economics drew on his background in physics. Given these circumstances, Tinbergen's article raises a number of questions. What drove Tinbergen towards working in economics? How did this training as a physicist influence him in that move? Why did Tinbergen's have such faith in mathematics? And why did Tinbergen publish this in an explicitly socialist medium? This thesis will argue that these questions cannot be answered apart from each other. Jan Tinbergen's transition from physics to economics was motivated in part by his political beliefs and in part by the particular contribution that physics could potentially have in the economic science. But at the same time, Tinbergen's transition took place against the backdrop of a broader change in academia: while academic research had long been a relatively isolated enterprise, societal and philosophical developments of the 1920's embedded academics into the fabric of society.

1.2. Relevance

A study into Tinbergen's transition from physics to economics is especially relevant because very little research has been done into his early years. Some major exceptions are the work of Marcel Boumans (specifically 1989 and 1992) on Tinbergen's socialist beliefs and the way he used the physical method in his economic writings; Jolink's (2003) book on the 'statistical turn' that Tinbergen incited in economics; and Hollestelle's (2011) dissertation on Paul Ehrenfest. This thesis has benefited greatly from their work, but also hopes to complement it. Boumans' 1989 article is very instructive, but only briefly treats Tinbergen's political beliefs during the period with which this thesis is concerned. Boumans' 1992 work is largely methodological: it discusses *how* Tinbergen used physical methods in economics, but not *why* he wanted to move into economics to begin with. While Jolink's work contained biographical information that was very valuable for this thesis, both on Tinbergen's life until 1922 and on his early political engagements, most of the book is concerned with his later scientific work. Hollestelle, finally, treats Tinbergen in a chapter of Ehrenfest's interest in economics, which means that the greater emphasis is on Ehrenfest. Most other works on Tinbergen start in the 1930's, when Tinbergen was already a renowned economist.

As a historical study about Jan Tinbergen, this thesis hopes to complement these works with two contributions: firstly, by treating a period in Tinbergen's life that has received little attention and, secondly, by integrating different aspects behind Tinbergen's move from physics to economics.

In addition, this thesis may offer substance to two contemporary debates: the debate regarding the relation between economic science and policy, and the place of mathematics in economics. Let me briefly discuss these in turn.

In recent years, the influence of the economic science on policy has been subject to increasing scrutiny. This is perhaps not surprising, since economics has become more and more important in public decision making: the economic calculations of the Dutch Central Planning Bureau (CPB) can make or break policy proposals, cost-benefit analyses are used to quantify the value of everything from wildlife to human lives and economists have become widely respected experts for policy on almost any domain. Opinions are divided about the extent to which that is an improvement. On the one hand, economists advise us how to spend scarce resources most effectively. On the other hand, some fear that important political decisions that affect the distribution of wealth and societal justice have been replaced by experts and models, and inadequately so[2].

Jan Tinbergen's case is interesting because it stands at the beginning of this trend. In fact, Tinbergen was effectively confronted with the opposite challenge: the factual basis of political debates was limited, and one of Tinbergen's greatest contributions was that he played a role in changing that. Studying Tinbergen can aid contemporary public debates by showing what he considered to be the advantages of economically informed policy.

There has also been unrest about the role of mathematics within the economic discipline. The use of mathematics in economics has increased enormously over the past century. While we will see that one of Tinbergen's articles was accepted under the condition that he simplified his use of mathematics ('De Roulering in het Werklozenleger', 1928) – economists, after all, had barely any mathematical training and needed their theories expressed in words - modern economic articles rely heavily on the use of mathematics. According to some, this may have had severe drawbacks. In the wake of the financial crisis, Paul Krugman infamously attributed part of the crisis to the fact that "economists, as a group, mistook beauty, clad in impressive-looking mathematics, for truth" (2009). Economists had pushed the use of mathematics so far that it was no longer always useful, but often a goal in and of itself. In particular, the mathematization of economics had made economists lose track of reality.

This is, of course, a rather dramatic and one-sided picture. Not all aspects of economics have been so thoroughly mathematized; different domains of economics make use of different kinds of mathematics and in many cases, surely, this will have served a constructive end. But the sentiment that Krugman here represents does mean that the use of mathematics in economics is now a topic of debate. While Tinbergen was not the first to introduce mathematics in economics, he did introduce some new defenses and qualifications for the use of mathematics that may be insightful for this debate.

1.3. Method

The central research question of this thesis is why Jan Tinbergen moved from physics to economics. A number of methodological decisions have been made to make this study feasible and presentable.

First of all, with regards to scope, this study will consider Tinbergen's life and work between 1922 and 1930 (with some exceptions). This decision was made to do justice to the broad spectrum of factors that play a role in Tinbergen's transition. This period roughly covers Tinbergen's co-operation with Paul Ehrenfest, from his employment as his assistant in 1922 to one year after the publication of his dissertation in 1929.

Secondly, with regards to presentation, this study will treat Tinbergen's transition from physics to economics in three chapters with individual *themes*, as contrary to chapters that cover individual *periods*. This was motivated by the breadth of the topic: because each theme needed its proper context, a chronological history would risk becoming incoherent as each theme would only be treated intermittently. Treatment in themes has hopefully led to a more integrated and richer analysis, and

[2] Some broad examples are Nussbaum (2001), Richardson (2000), Klaver (2015).

allowed me to shed light on the additional question how Tinbergen's background in physics influenced his political and economics writings. This does not mean that it is without trade-offs. The current structure risks undervaluing the extent to which the different themes are related. In order to compensate, I will occasionally refer backwards and forwards to other parts of the text for which a particular passage or article will be relevant. I hope this will not distract the reader too much.

As primary material for this thesis, I made extensive use of Tinbergen's political and economic writings. The catalogue in Marcel Boumans' dissertation (1992) was especially helpful for locating many of them. Some writings were available online: De Socialistische Gids and Het Volk are available online through Delpher, the search engine of the Koninklijke Bibliotheek. De Economist and Mensch & Maatschappij were both accessible online through Google Scholar. In order to access Tinbergen's writings in Kentering, I visited the International Institute of Social History (IISG) in Amsterdam. Citations from letters sent by or addressed to Tinbergen are either cited directly, after visits to the Boerhaave Museum's Ehrenfest archive and the Tinbergen archive in Rotterdam, or indirectly through other sources. I have referenced letters and images independent from the bibliography.

This study is built up as follows: the second section will introduce Jan Tinbergen and his mentor, Paul Ehrenfest, with a brief biography. The third section will argue that Tinbergen's move from physics to economics should mainly be seen as an attempt to unify his political and academic persona. Tinbergen had a clear picture of what it meant to be a good socialist, and his move from physics to economics followed from his attempt to conform to it himself. This section will also show how his background in physics influenced his political beliefs – in part through Ehrenfest. The fourth section puts Tinbergen's move from physics to economics in the context of the changing role of academics and the university. The public perception of the university and the academic was changing in the early 20th century. On an institutional level, this was represented by an increasing engagement with public life, even among natural scientists. On a philosophical level, this was represented by the search for *synthesis*: the quest for unifying relations across scientific disciplines and society. Tinbergen's work fits into both. The fifth section will illustrate how Tinbergen's work in economics made use of his background in physics. In line with the epigraph, it will show where, but also how, Tinbergen made use of his physical background in his early economic work. While Tinbergen was certainly not the first to draw on physics for economic writings - the interaction between physics and economics had a history that went back to the 19th century - I will argue that his method was innovative, and that his faith in the added value of mathematics for economics drove him towards that field.

2. Jan Tinbergen & Paul Ehrenfest

This section will offer biographical information about Jan Tinbergen and Paul Ehrenfest. For Jan Tinbergen, this section will cover the period from his birth to the start of his assistantship with Paul Erhenfest (1903-1922). For Paul Ehrenfest, this period will cover his entire life (1880-1933). This extensive treatment of Ehrenfest is warranted because he will be a returning actor throughout this study: Tinbergen was Ehrenfest's assistant from 1922 to 1929, and the two remained friends until Ehrenfest's death in 1933. Ehrenfest also had a distinct interest in economics, even though his interest is arguably of a different nature and his writings were never published. Much of Tinbergen's early academic formation in economics came, nonetheless, from the books that Ehrenfest recommended him. Ehrenfest, too, had a political interest (albeit less pronounced and passionate than his student) and was moved by the changing public position of academics. In many ways, Tinbergen's development resembled the interests of his mentor, who is for that reason inevitably an important part of this study.

2.1. Jan Tinbergen's Early Life

Jan Tinbergen was born in The Hague on the 12th of April of 1903 to a family of teachers[3] (Jolink, 2003). Dirk Tinbergen, Jan's father, was a university-educated linguist, who worked as a teacher at the Hoogere Burgerschool in The Hague. As a linguist, het contributed to the editing of Medieval Dutch texts: the well-known fable of the fox Reinaert is among the works to which he lend his hand. His main passion was, nonetheless, teaching, as it was for his wife. Jeannette Tinbergen, neé van Eek, had been a primary school teacher in the years before her marriage. Her occupation in the small fisher's village of Scheveningen had shown her the poverty under which many of its inhabitants lived, which led her to employ occasional social projects in the region. Jan and the other children were occasionally asked to contribute, which Jan later described as his first 'social immersion'. The Tinbergen's passion for teaching was reflected in the family as well: Dirk and Jeannette encouraged their five children to develop themselves and to explore new opportunities, guided by the ideas of the Dutch didactician Jan Ligthart. And how the Tinbergen children used those opportunities: Niko Tinbergen studied biology and became a university professor in Oxford, winning the 1974 Nobel Prize for Physiology or Medicine for his work on animal behavior. Dik Tinbergen became an engineer and managed the municipal energy company of The Hague, while Luuk Tinbergen became a professor of Biology at the University of Groningen. Jacomien Tinbergen studied German and would follow her father in becoming a high school teacher.

It was clear quite early on that Jan's interest lay in the natural sciences. During his high school years, he attended the regular science gatherings of the so-called 'Faraday Club' and was interested in the

[3] Unless specified otherwise, the biographical information here presented is due to Jolink's 'Jan Tinbergen: the Statistical Turn in Economics: 1903-1955' (2003).

developments of relativity theory, which had only just entered into academic circles. Simultaneously, Jan's interest in social affairs came to gain momentum. Tinbergen was critical of militarism and the army in general. He also thought Christian and liberal politicians were too negative about socialism. The same double interest in science and society continued during Tinbergen's time at the University of Leiden. Given Tinbergen's background and interests, the choice for that university was obvious: not only was his father an alumnus, it was also the university of Lorentz and Kamerlingh-Onnes. Tinbergen finished his *Candidaats*-education, which is comparable to a two-year Bachelor degree, in one year, allegedly in order not to burden his parents with paying for his education. This rather extraordinary achievement did not go unnoticed by Paul Ehrenfest, who would guide Tinbergen through his further education in physics.

2.2. Paul Ehrenfest

The impressive yet tragic life of Ehrenfest is the subject of a biography by Martin J. Klein (1970). Ehrenfest was born in Vienna in 1880[4], the youngest to a Jewish family of grocers. To those close to him, it was soon clear that young Paul's nature was volatile. Paul was plagued by depressions early on, and the tendency towards depression continued to plague him throughout his life - eventually leading him to take his own life in 1933. At the same time Paul Ehrenfest was known as an intensely passionate person, in particular about his work. This, like his darker tendencies, was evident at an early age: young Paul Ehrenfest could get very passionate about selecting the best eggs for his parents when he went shopping, and was very happy when his count for the amount of sugar that had been delivered turned out to be exactly right. Both the lighter and darker tones of Ehrenfest's youth persisted throughout his life, in which his vacillation between passion about his work and depression about life became an important theme. Paul Ehrenfest was first introduced to physics through one of his four older brothers, Arthur, who was seventeen years his elder and an engineer. While the young Paul Ehrenfest devoured books as soon as he could read, it was from the practically oriented Arthur that he first learned physical concepts. Paul's interest for physics and mathematics got stronger during his adolescent years, when they were a welcome distraction from his emotional struggles. In 1899, he registered for the Technische Hochschule in Vienna where he studied until 1911, in particular with Boltzmann until his death in 1906. Boltzmann is best known for his role in developing the field of statistical mechanics, which discusses the behavior of thermodynamic systems in terms of the statistical properties of the system as a whole instead of in terms of the behavior of the individual particles, as classical mechanics would do.

When Ehrenfest started looking for a permanent position in 1911, it became clear immediately that academic positions were difficult to attain. The University of Leipzig, one of the first universities where Ehrenfest inquired, only considered applicants with a German degree; the University of Munich refrained from accepting outsiders so as not to limit the chances of their own students. The University of Prague, finally, required applicants to have a religious affiliation, which Ehrenfest had given up in order to

[4] Unless otherwise specified, the material in this section stems from Martin Klein's 'Paul Ehrenfest: the Making of a Theoretical Physicist' (1970).

marry his wife, Tatyana. Tatyana Ehrenfest, née Alexeyevna, and Paul Ehrenfest had married in 1904. With her background in mathematics, Tatyana Ehrenfest would prove to be a very valuable sparring partner. Some publications, such as a 1911 article for an encyclopedia by the German mathematician Felix Klein, even bore both their names.

It was in 1911 that Ehrenfest was contacted by Lorentz, who then held the chair of theoretical physics in Leiden, with a seemingly unimportant inquiry about the state of physics in the Moscow area. Lorentz and Ehrenfest had met before, in 1903. Unbeknownst to Ehrenfest, the real reason behind Lorentz' letter was that he was considering him as his successor in Leiden. Lorentz had decided to step down after an exceptionally fruitful career, and started considering Ehrenfest when his first choice, Albert Einstein, accepted a position in Zurich. Lorentz had read and was impressed by Ehrenfest's encyclopedia entry. In addition, Ehrenfest was warmly recommended by Sommerfeld. Sommerfeld did not know Ehrenfest very well, despite the fact that the two had been in touch over Ehrenfest's interest to join the University in Munich. Sommerfeld mainly based his kind words on the reputation Ehrenfest had gained amongst others, who praised his clear mind and exceptional teaching skills. When Lorentz unveiled his intentions in his second letter to Ehrenfest, the latter was overcome by excitement. He immediately replied that he would accept the offer without conditions, except if he was offered a Swiss position in the meanwhile. Ehrenfest's nervous nature became clearly visible in this exchange of letters. On some days he was intensely excited with the prospect of succeeding a great scientist like Lorentz at such a renowned university as Leiden. On others he was driven mad by the delay in Lorentz' answers, sometimes even thinking he had had second thoughts; or he was daunted by idea that he was to live up to Lorentz' immense reputation. This uncertainty about his own abilities as a physicist - which were not doubted by anyone else but him - haunted him throughout his Leiden professorship, which he formally accepted on the 4th of December of 1912. Ehrenfest became known as an exceptional teacher, with excellent rhetoric skills and a contagious enthusiasm. He was interested in the well-being of his students, organizing regular meetings at his own house and reinvigorating the student organizations *Christiaan Huygens* and *De Leidsche Flesch* (Hollestelle 2011). More generally, Ehrenfest had a distinct interest in pedagogy. Many of the colloquia that he organized in his own home were on that topic. His views on the relation between theoretical education and practical use will return in a later section.

Despite all these accomplishments, Ehrenfest's disposition towards depression continued to plague him. They came to a climax in 1933, when, like his mentor Ludwig Boltzmann 27 year earlier, he took his own life after taking that of his younger son, Wassik.

Before his untimely passing in 1933, Ehrenfest had made numerous contributions to statistical mechanics and the developing field of quantum mechanics. In 1911, Ehrenfest finished an article for the encyclopedia of the German mathematician Felix Klein, in which he amongst others defended Boltzmann's so-called 'H-theorem' against the accusation that Boltzmann's conclusion that entropy always increased was at odds with the time-invariance of the laws of mechanics. Given a set of particles with particular positions and particular motions within a thermodynamic system, Boltzmann had held that entropy should always increase – so if a system that moves from t to t+1, entropy should increase. But the principle that the laws of mechanics are time-symmetrical held that mechanical laws are independent of whether we move from t to t+1 or vice versa. Since the reversed movement from t+1 to t would decrease entropy, which Boltzmann's H-theorem did not allow for, the reversibility-problem posed a challenge for statistical mechanics. In a 1911 article, the Ehrenfests responded that Boltzmann's H-theorem should not be taken to hold that a reduction in entropy is *impossible*, but that it is very, very improbable. In the same year, Ehrenfest wrote an article on Planck's quantum hypotheses. In his discussion of black box radiation, Planck had introduced the assumption that electromagnetic radiation would only be given off in discrete packages of e = nhv where e is the radiation, m is a positive discrete number (0, 1, 2, etc), h is Planck's constant and v is the frequency. While Planck had introduced this as a mathematical convenience that one could in principle dispense with, Ehrenfest showed that this assumption of discreteness should have a physical interpretation in order for Planck's conclusion to hold. Unfortunately for Ehrenfest, Poincaré independently arrived at a result that was considered similar only a few months after Ehrenfest's publication. To Ehrenfest's great disappointment and frustration, Poincaré got most of the credit. In 1913, Ehrenfest contributed to a physical interpretation for the discreteness of variables within particular physical systems with his 'adiabatic hypothesis'. Ehrenfest pointed out that some physical systems contain variables that do not vary when parameters are changed sufficiently slowly. These 'adiabatic invariants' only change their value when a 'shock' is admitted to the system. The discreteness of Planck's energy packages could be a particular example of this more general principle: only energy levels that exceed a discrete threshold could make the adiabatic invariant change its value. While little attention was initially paid to Ehrenfest's adiabatic hypothesis, which he considered to be his greatest contribution to physics, it was picked up by Niels Bohr in 1918. The adiabatic hypothesis has since been acknowledged as an important innovation in the emerging field of quantum physics.

There is ample evidence to suggest that Ehrenfest had an interest in economics, even though he never published on the topic. One reason for this interest was the relation between economics and physics. In 1918, Ehrenfest first mentioned that he was interested in economics in a letter to his close friend, Albert Einstein. Ehrenfest was convinced that there were parallels to be found between thermodynamics and economics. Though he never published any work of economics, his notebooks are filled with attempts to relate concepts from thermodynamics to concepts from economics. According to Klein, Ehrenfest read the works of (amongst others) Böhm-Bawerk, Schumpeter, Marx and Taussig, and possessed works by the Marxist Werner Sombart and the German economist Ehrenberg, whose work he read in 1904. According to Hollestelle[5], Ehrenfest's had a slumbering interest in economics as early as in 1904 but was only seized by the topic near the end of the next decennium. Ehrenfest worked on nothing but economics between October of 1917 and May of 1918.

There are a number of potentially co-existing opinions on Ehrenfest's motivation for working on economics. These views will return later when we discuss Tinbergen, but it may be helpful to introduce them briefly here. According to Klein, it was Ehrenfest's desperation about his own ability to contribute to the rapidly changing field of physics that drove him to a different discipline. Ehrenfest, who had undergone most of his training in classical and Boltzmann's tradition of statistical mechanics, was

[5] The remainder of this section builds on Hollestelle (2011).

skeptical about the upcoming field of quantum mechanics. Ehrenfest felt that quantum mechanics had elevated mathematical treatment to a purpose in itself, and that it lacked a clear relation to physical concepts. In one of his darker periods, Ehrenfest felt that his mathematical skill was not adequate for this new kind of physics. In addition, Ehrenfest was disappointment with the lukewarm reception of his 'adiabatic hypothesis'. This helps us to understand why Ehrenfest left economics behind in 1918, when he received a letter from Bohr announcing his use of the adiabatic hypothesis in one of his articles. Bohr's letter returned some of Ehrenfest's hope for physics, and he quickly returned to physics.

If we accept Klein's explanation of why Ehrenfest wanted to escape physics, it is no coincidence that it was economics that he turned to. In a letter to Schumpeter, which Jolink (2003) cites, Ehrenfest underlines this (3rd of May 1918, ESC10:146):

> "I am particularly interested in theoretical economics because it conforms to mathematical physics and because, methodically, it has several points of contact especially with a theoretical physics discipline which has kept me occupied for a long time: Thermodynamics (the study of thermal equilibrium and energy transformation)" (cited from Jolink (p. 27); Ehrenfest's emphasis)

As we will soon see, Ehrenfest would not be the first to become interested in the similarity between thermodynamics and particular parts of economics. This similarity will become an important theme in my later discussion.

A second factor in Ehrenfest's interest in economics were his educational views. According to Hollestelle (2011), Ehrenfest's interest in economics should also be seen in the context of his educational philosophy. Ehrenfest believed that a thorough theoretical education in a pure science was the *sine qua non* for the practical application of science. On Hollestelle's interpretation, Ehrenfest saw economics mainly as a practical extension that could potentially follow one's education in physics. Finally, Ehrenfest's social engagement may be a factor. According to Ehrenfest himself, his two main motivations for working in economics were his interest in the living conditions of the proletariat and his own personal background as a grocer's son in Vienna (Van Lunteren & Hollestelle 2013). In addition, Ehrenfest was known as the 'red professor' for hosting students with socialist sympathies.

Whatever Ehrenfest's motivations for entering economics may have been, it is certain that Ehrenfest would prove helpful to Jan Tinbergen's first steps in economics. Some of this help consisted out of readings: Ehrenfest had introduced Tinbergen to the works of Bowley, Wicksell, Pareto, Barone and Roos (letter from Tinbergen to Ehrenfest, 16th of February 1930, ESC10:2 as cited by Boumans 1992 p. 11). But Ehrenfest also was Tinbergen's sparring partner. Jolink (2003) traces joint discussions on reformulations of Pareto optimality, an important concept from welfare economics, to a letter from Ehrenfest to Tinbergen in November of 1925. Ehrenfest also commented on at least one economic article that Tinbergen wrote for 'De Economist' ('The Economist'), a Dutch economic journal, in 1928 (Letter from Tinbergen to Ehrenfest, 2nd of November 1928, ESC9:384). The interest is mutual: in April of 1930, Ehrenfest sends Tinbergen a note in which he asks him to remind him about a particular economic theory they had once discussed, and which involved "exchange" and "indifference curves" (ESC10:5, letter from Ehrenfest to Tinbergen, 21st of April 1930).

Paul Ehrenfest and his students. From left to right Gerard Heinrich Dieke, Samuel Abraham Goudsmit, Jan Tinbergen, Paul Ehrenfest, Ralph Kronig and Enrico Fermi.

Figure 2

Ehrenfest supervised Tinbergen's dissertation, titled 'Minimum problems in Physics and Economics' (1929). The majority of this dissertation discusses different varieties of minimum problems as they appear in physics. The treatment of economic problems is confined to the appendix. Again, different accounts exist about Ehrenfest's attitude towards this endeavor into economics. According to Jolink (ibid), Ehrenfest had tried to 'cure' Tinbergen of his fascination with economics by sending him to Göttingen in 1923. Similarly, Alberts (1998) calls the economic appendix a 'compromise', suggesting either that Tinbergen would not have wanted to write a physics thesis or that Ehrenfest did not appreciate Tinbergen writing about economics (n134 on p. 128).

The last scenario seems implausible. Aside from the fact that Ehrenfest had devoted a considerable time to economics, he also wrote Tinbergen about his dissertation in March of 1929 – when Tinbergen was finishing up - saying that "the fact that it also contains economic problems, that are not being treated in textbooks about mathematical economics, makes it all the more interesting." (ESC9:404, letter from Ehrenfest to Tinbergen, March 2nd 1929). Ehrenfest added that he would recommend it to his students. Four years earlier, Tinbergen had sent a letter to Wicksell in which he mentioned that he was "allowed" to continue studying "mathematical economics", "at the instigation of Professor Ehrenfest" (23rd of June 1925, as cited by Jolink (p. 26)). Finally, Ehrenfest wrote with great enthusiasm about the path that Tinbergen had followed from physics to mathematical-statistical economics – he called it the

"Tinbergen-goal" – in a letter in 1929 (ESC9:406, Letter from Ehrenfest to Tinbergen, 20th of March 1929). As we will later see, Ehrenfest and Tinbergen even contemplated founding a program that would allow others to follow in Tinbergen's footsteps. Given all these signs, it seems unlikely that Ehrenfest objected to the fact that Tinbergen worked in economics.

3. A Physicist in Political Circles

This section will show that Tinbergen's political beliefs were an important driving factor behind his move from physics to economics. The first section (3.1.) will elaborate on the state of socialist political and economic theory around the time Tinbergen entered into politics and offer evidence of Tinbergen's early and active involvement in socialist (youth) politics. It will also show that his economic aptitude was already advanced by discussing a number of articles on unemployment. Finally, it will argue that his early work was characterized by a pragmatic approach. The second section (3.2) will show that Tinbergen had particular ideas about what it meant to be a good socialist. In particular, he believed that a good socialist should put his or her socialism ahead of their other occupations, which challenged him to resolve the tension between Tinbergen the socialist and Tinbergen the physicist. In addition, this section will show how his approach to politics was colored by his background in physics, and in particular by his mentor, Paul Ehrenfest.

3.1. Tinbergen the Socialist

3.1.1. Marxism and Socialism in the 1920's

In order to understand Tinbergen's political interests, it is helpful to sketch the context in which he found himself – the political climate of the Netherlands in the early 20th century, and in particular its socialist parts. The state of socialist theory in 1920 is best characterized by a loss of certainty – certainty, in particular, about the concept of socialization. Socialization refers to the process through which the means of production would be transferred from capitalist owners into public ownership. According to Orthodox Marxism, the achievement of socialization was a matter of time; it was a scientific certainty that could be deduced from Marx' historical-materialist premises. Tinbergen entered into politics during a period in which socialists became open to alternative accounts.

Verwey-Jonker (1938) distinguishes three generations of socialist theoreticians around this time period. For the first generation, the inevitability of socialization was beyond doubt. For some, this was because they considered the socialist doctrine as a scientific truth; for others, this was rooted in cultural optimism. The second generation was more hesitant. Verwey-Jonker calls them "generally weak in terms of theory" (p. 346), because they did not approach socialization from the scientific, historic-materialistic and complete framework of Marxism, but from individual narratives. Members of the second generation did not openly doubt whether socialization was achievable, but their allegiance to it was more a matter of faith than a belief in its inevitability. This tendency to stray from Marxist doctrine was carried further by the third generation, which no longer believed in the certainty of socialism. A socialist system would be preferable, on ethical grounds, but the transition to a socialist system was by no means guaranteed. This generation was no longer content with hopes and promises, and required concrete proposals and results. Tinbergen would become, according to Verwey-Jonker, this generation's most prominent exponent.

This development from the certainty of doctrine to an attempt to defer to the facts was not only present in socialist political theory. Socialist economics was affected too, as Kalshoven's study of Dutch Marxist economics between 1883 and 1939 shows. On a general level, Kalshoven distinguishes between three periods in the 'rise and fall' of Marxist economic theorizing in The Netherlands. Until 1900, Marxism in The Netherlands was of limited importance in the public debate, amongst others because reformists in the SDAP ('sociaal-democratische arbeiderspartij', or social democratic labor party) had little patience for theory. This changed after the turn of the century, when Marxists within the labour movement found a platform for discussion in an independent magazine called 'De Nieuwe Tijd' ('The New Times'). Exchanges in its pages, between thinkers like Saks, Van Gelderen, De Wolff and Kuyper, led to what Kalshoven calls 'Dutch Style Marxism'.

The movement came to a halt around 1916. First of all, while 'De Nieuwe Tijd' had officially been independent, its reader- and authorship was found mainly among those sympathetic to the SDAP. This meant that De Nieuwe Tijd found itself facing stiff competition when, in 1916, the SDAP founded its own magazine: 'de Socialistische Gids' ('The Socialist Guide'). Contrary to the editors of De Nieuwe Tijd, the editors of the Socialistische Gids were not favorable to Marxist theorizing. The founding of de Socialistische Gids thus led to the decline of the Marxists' podium for debate. Two other factors were the unfulfilled promise of socialist cooperation in the aftermath of the First World War and the failure of the Dutch socialist revolution by SDAP-leader Troelstra in 1918. This last events had severely embarrassed the SDAP and in particular the (Marxist) revolutionaries in its midst, and led the party to accept a more moderate course.

The prominence of Marxism in economics decreased in the period that followed. In a movement that tracked the SDAP's turn from revolution to reform – where socialists turned into social-democrats - economists of the left started to apply 'mainstream' economic tools to socialist dilemma's, rather than to insist on the use of the Marxist terminology and method.

The political climate of Tinbergen's early twenties had not lost faith in the desirability of socialization itself – and neither had Tinbergen[6], as becomes clear from a two-part exposition in Kentering that Tinbergen co-wrote with his co-editor Oudegeest Jr. in 1925 and 1926, and which will be treated in section 3.1.4. But at the same time, the climate was changing. On the political level, socialization was no longer seen as an inevitability, which opened social-democrats to alternative routes to public ownership of the means of production. Within socialist economics, socialist economists became more receptive to the use of non-Marxist terms and methods. It is under these circumstances that Tinbergen would enter political life.

[6] This would later change: by 1937, Tinbergen believed that "no social-democrat still believes in complete socialization" (Tinbergen 1937, p. 616).

3.1.2. Tinbergen's early entry into Politics

Around the same time at which Tinbergen became Ehrenfest's assistant, he joined a number of student organizations. Many were affiliated with the socialist cause. Tinbergen joined the SDAP in 1922 together with his then girlfriend and later wife Tine. In his student years, Tinbergen's was mainly involved with socialism through his participation in various socialist student organizations. Tinbergen for example co-founded the Social Democratic Student Club (SDSC), which wanted to help transform the Netherlands to a socialist society. Tinbergen also joined debating society 'Christiaan Huygens', where he first discussed the notion of 'mathematical economics'. His audience was, unfortunately for him, not all too sympathetic:

> "After the tea had been served and the cookie tins had gravitated in opposite directions, the first sacrifice was led to the slaughter, that is, to the blackboard. His presentation was shouted out and greeted with mockery. Initially some showed interest but at the end most disregarded him completely. The most important words during the presentation were: utility, function and differentiation. (…) While the speaker tried very hard to transfer all these thing of 'mathematical economics' from his memory to his mouth, he was abruptly interrupted by loud knocking on the door." (Minutes of the Christiaan Huygens Debating Society, 1923, Christiaan Huygens Archive, Leiden; as quoted from Jolink (p. 21)).

It served him better to expound his ideas in writing. Tinbergen published articles in both socialist and scientific journals and periodicals. His political writings were published in Kentering, Het Volk ('The People') and de Socialistische Gids. Tinbergen was a regular contributor of Kentering since its establishment in 1924, and served as its editor of its second year of circulation between October 1925 and October 1926 together with J. Oudegeest junior[7]. He would also be elected editor of the Socialistische Gids in 1929 (Jolink 2003).

3.1.3. Unemployment

Tinbergen's political writings show that he was not only very laborious, but also had an advanced understanding of economic theory – especially for someone without any formal education on the subject. This can be illustrated by looking at a sample of his articles on the topic of unemployment, an especially prominent topic in his early writings.

Tinbergen published five articles on the topic of unemployment in Het Volk, all in the short timespan between July of 1927 and 1928. Tinbergen had written on the topic earlier, in a series of descriptions of the life of the unemployed that was published in Het Volk between November of 1925 and February of 1926 (and a brief version, 'Uit een Andere Wereld', in Kentering in March of 1926). While those articles

[7] While Oudegeest's first name has been difficult to find, the affix 'Jr.' suggests that he was the son of Jan Oudgeest, who would later become party leader of the SDAP. Tinbergen and Oudegeest resigned in October of 1926 due to "naughty study plans" (Redactie Kentering, 1926)

mainly showed his deep-felt support for the unemployed, the series of five articles that will be discussed here show a thorough understanding of the possible causes and solutions of this economic problem. This positions unemployment as the most important topic within Tinbergen's political writings.

The first article (July 1927) defended the payment of premiums to private companies that were willing to employ the unemployed, following the example set by Austria in 1926. This premium, a maximum of ¾ of the premium, would otherwise be paid in the form of unemployment benefits, and could be seen as a way to counter the negative effects on employment that were caused by high import tariffs of surrounding countries. It was, in any case, to be preferred over imposing high import tariffs at home, because that would increase inflation. While this article discussed a particular policy that would combat unemployment, the second article (August 1927) was more general. It reviewed a number of known causes of unemployment, with the particular aim of distinguishing the different solutions of bourgeois ('burgerlik') politicians and socialist. According to Tinbergen, bourgeois politicians and socialists agreed that employment mediation, public investment and unemployment insurance could diminish unemployment or at least remediate some of its negative effects. If these measures were undertaken, there would still be a residue of unemployment as a consequence of oversupply of labor: 'permanent unemployment'. This permanent unemployment could in principle be countered with population policies (lowering population growth would lower the labor supply; Tinbergen remarked that attempts in this direction had been unsuccessful, and should be a last resort), technological development (which cannot be controlled) and, finally, by redistribution. It is on that subject that bourgeois politicians and socialists are divided. Bourgeois politicians wanted to lower unemployment by lowering wages and thereby increasing demand, while socialists doubt that this would work: they saw permanent unemployment as a necessary implication of the capitalist system, in which the existence of unemployed labor served as an implicit threat for capitalist workers by reminding them that they were expendable. Instead, socialists pleaded for public investments and the reduction of the workweek. These policies would redistribute the 'pain' caused by unemployment over society as a whole.

The third article (February 1928) zoomed in on the relation between unemployment and the number of intermediaries in the Dutch market for consumer goods, which was relatively high compared to the United States, England and Germany. According to Tinbergen, this was because the ideal of having a business is part of the Dutch culture, and is often seen as a good alternative to unemployment. The problem, however, was that a high amount of intermediaries drives the price of consumer goods upwards. More links in the chain between producer and consumer meant, after all, that more people have to earn money. In addition, Tinbergen held that the high amount of intermediaries means that each has an exceedingly small share in the market, so that each intermediary has to increase its prices in order to arrive at a level of revenue with which they could sustain themselves. This price rise would be enthusiastically followed by other intermediaries who feel equally pressured to increase revenue, so that the price of consumer good would go up across the board. The presence of a high number of intermediaries did therefore not only bias unemployment numbers, but also induced inflation. Tinbergen did not consider particular solutions to the problem, other than to emphasize that socialists needed to pay attention to the structure of the market in the development of their thoughts.

The fourth article (June 1928) and fifth article (September 1928) returned to the endeavor of the second article, and discussed policies that could decrease unemployment. The fourth article mainly considered subsidized labor, in which the unemployed would be hired by the state to perform works that either would not be provided by the market (Tinbergen mentions the example of housing for the rich) and works that improve the general infrastructure of the economy (Tinbergen mentions the improvement of soil, roads and canals). This confinement to particular kinds of works was testimony of Tinbergen's awareness that this form of public employment should not crowd out private employment. The other policies that Tinbergen mentioned were a reduction of the working week, more vacation days and an extension of the law on compulsory education. The fifth article addressed the suggestion to reduce the working week at greater length. Tinbergen believed that recent history had shown that it is difficult to increase employment in general, and that it would be best to distribute the resulting unemployment in such a way that no individual would be unemployed for an extended amount of time.

Despite the fact that these articles were short – Het Volk was a daily newspaper – Tinbergen managed to attain an impressive level of depth for 24-year old without any formal training in economics. He carefully distinguishes different kinds of unemployment, is aware of important disadvantages of both the state and the market and is well-versed in the intricacies of the price mechanism. These articles also show his tenacity for the topic, as well as how well-informed he is about national- and international debates.

Tinbergen would give unemployment an even more analytic treatment in a 1928 article in De Economist, 'The Rotation of the Army of the Unemployed' ('De Roulering in het Werklozenleger'). In this article Tinbergen pointed out that numbers about the number of unemployed at any given point in time do not give a complete picture of the issue of unemployment, since people who were unemployed for a long time should be considered more problematic than those who were unemployed only briefly. Tinbergen then turned to a study of the unemployed in Amsterdam in 1926, which had surveyed how long different respondents had been unemployed at the time of measurement. Tinbergen stated that even this kind of information was not enough, since it did does not take into account the duration of the unemployment that followed the measurement period. Having given this overview, Tinbergen distinguished three different kinds of distributions pertaining to the measurement of unemployment. Firstly, in line with the survey in Amsterdam, there was a 'distribution A' which measured, for all sampled unemployed respondents, the length of time for which they have been unemployed until the point of measurement (e.g. there are n instances of unemployment of length x, m instances of unemployment of length y, etc.). Secondly, there was the 'distribution B', which was the distribution of time over instances of unemployment in general (e.g. n periods of x duration, m periods of y duration, etc.). Thirdly, there was 'distribution C', the distribution of the number of unemployed as ordered by the duration of unemployment at the point of measurement (e.g. n individuals are unemployed for a duration of x, m individuals are unemployed for a duration of y, etc.). The article continued by relating these different distributions to each other, under the assumption that the distribution of unemployment remained the same. Tinbergen explained that distribution B can be derived from distribution A by appreciating that from B we can calculate the amount of individuals that finds employment after every unit of time; and by translating that number to number of months unemployed per individual, we find distribution A. One can arrive at distribution C from distribution B by imagining how both change over an extended period of time. B counted all unemployed only once, because it only took into account the accumulated period of their unemployment. C counted them more often, because it counted an individual once for their first time unit of employment, another time for their second time unit of employment, and so on. In fact, C counted individuals as often as the amount of time units for which they are unemployed – and that was distribution B. Tinbergen himself summarized the relations as follows: "Mathematically, the relation between the three distributions is as follows: if x is the duration of unemployment (in the sense of the relevant distribution) and ydx the percentage of unemployed that finds a job between x and x + dyx, then [A] : y = f (x), [B] : y = - b f' (x) and [C] : y = - c x f' (x), where b and c are constants such that the total becomes 100%, and where the intervals [between x and dx] are considered to be infinitely small" (p. 777, my translation)

This brief overview of some of Tinbergen's articles on the topic of unemployment shows that Tinbergen was sincerely vested in this debate, and that he had a thorough understanding of its economic aspects for someone without any formal training in economics. The mathematical aptitude he professed in an earlier version of 'Roulering in het Werklozenleger' in writing this last article, furthermore, was so advanced that the editors of De Economist had asked him to tone it down.

> "here (…) one sees the opposition between the mathematician, who likes to express matters briefly, and the economist, who at least in this country has no mathematical training, and would like things to be expressed in words" (Letter from Verrijn-Stuart to Tinbergen, 22nd of July 1928, Erasmus University Tinbergen Letters, 001E007)

3.1.4. Socialism and Pragmatism

Tinbergen's focus on unemployment did not prevent him from having a broader socialist agenda. Together with his fellow editor, J. Oudegeest Jr., Tinbergen wrote an extensive article on his general approach to socialization. The article consisted of two parts. The first part (October 1926) sketched the status quo and the principles on which a socialist society should be built.

> "In a society organized according to socialist principles, the public should be in charge of production. As a guiding principle, it will be assumed that production serves the satisfaction of needs, now and in the future, and that every individual should partake according to his strengths. So:
>
> a. No income without labor, and no forced unemployment: the right to labor.
> b. Reasonable needs should be satisfied for all. Production should largely be determined ahead of time, in special cases free formation of prices may influence the details. (…)
> c. The system should comply with the demand of reproduction; what is worn down or used up should be reproduced every year;

d. Reserves should be made for necessary improvements, expansions and changes in needs." (p. 4, my translation)"

Tinbergen and Oudegeest Jr.'s proposal revolved around abolishing the free market as an organizing principle, even though they did not reject it completely. At the same time, they understood that the road *towards* such a state constituted an important part of the socialist challenge. The second part of their article, published in January 1926, contained concrete proposals for the transition and showed that its authors had paid close attention to the strategic aspects of a socialist transition. Firstly, Tinbergen and Oudegeest Jr. drew on the example of Sweden, where the railroad company had recently been socialized. The daily decisions of a socialized company would remain in the hands of the management, which would be accountable to a council of workers, technicians, consumers and members of parliament. While the management could decide on wages and tariffs, the council would have to approve of its budget. In addition, Tinbergen and Oudegeest Jr. believed that companies should not be socialized all at once, but branch by branch. Companies would initially still buy and sell products on the markets, but the free market would decline in importance as more and more companies were socialized. The first companies to be socialized were those which in effect already had a monopoly, as well as companies which met a particular stable and essential need for society, such as food. Finally, Tinbergen and Oudegeest Jr. believed that the owners of companies that would be socialized should be compensated. After all, owners who would not be compensated might be tempted to leave the company in a bad state, e.g. without supplies or with machines worn out. Such compensation could be funded through a tax on capital.

Tinbergen and Oudegeest Jr.'s article showed that they had a coherent socialist agenda. At the same time, it showed they were pragmatic. Instead of drawing an organizational form from theory, they drew on what was already practiced elsewhere; instead of insisting that all companies should be socialized at the same time, they proposed to socialize them branch by branch; and instead of simply nationalizing companies, they offered compensation to ensure that companies were turned over in a good state.

Tinbergen had to defend his willingness to be pragmatic four years later, in response to an article by Jacob van der Wijk. Tinbergen and others had castigated individual socialists for earning incomes that they considered too high for a good socialist. According to Van der Wijk, taking such an 'individual approach' towards socialization would only create 'socialist islands' in an otherwise capitalist society, and did not foster the broader socialist cause (Het Volk, 4th of August 1930).

Tinbergen response to Van der Wijk was twofold (Het Volk, 25th of August 1930). Firstly, Tinbergen said that criticizing socialists for their high incomes is merely a demand for consistency. If one preached that inequality in society should be minimal, one's practices should be the same. Secondly, Tinbergen pointed out that his plea for a particular moral regarding income will, in the end, facilitate the turn towards a socialist system:

> "the assertion, that the economic base of a society must be changed before the ideological superstructure can change, implies that the adaptation of the superstructure to the base only

occurs after a certain amount of time. The ideologies show a particular slowness, which represents the slowness of the human mind. This slowness can sometimes lead to difficulty. I believe that many of the problems in Russia have been a cause of it. It is also this slowness that makes socialism appear like impossible to some; these people do not believe that the human mind can change quickly enough after the change in circumstances. Working on the human mind today, in the socialist direction, to diminish this slowness in that decisive period of time seems to me to be a necessary consequence of understanding the relation between economic base and ideological superstructure; not to mention the retroaction of ideology on economic circumstances" (Het Volk, 25th of August 1930, my translation)

While this remark was intended as a retort against Van der Wijk, Tinbergen also made a broader point: in order to achieve their aim of a socialist society, socialists could not permit themselves to lose track of beliefs and practices that are inherent to the capitalist society. A gradual, piecemeal transition – branch by branch, with compensation for current owners – was to be preferred over more radical transitions that emphasize ideological certainty over pragmatic realism.

If Tinbergen was, as Verwey-Jonker claimed, the most prominent exponent of a new, more pragmatic generation of social-democrats, one can argue that this seed was already planted in the 1920's. The exchange between Tinbergen and Van der Wijk showed that Tinbergen was sensitive to the way socialist aims could be embedded in a –for now - capitalist society, even though he still acknowledged socialization as a long-term aim. The existence of 'socialist islands' in an otherwise capitalist society was not a rejection of socialism, but a way of attaining a fairer distribution of wealth in anticipation of further socialization.

3.2. The Good Socialist

3.2.1. Socialism as a Guiding Principle

In addition to having a clear approach to socialism, Tinbergen also had a clear picture of what it was to be a good socialist. As this section will show, this image of 'the good socialist' is an important motivating factor for Tinbergen's transition from physics to economics.

Tinbergen wrote on the topic of 'the good socialist', as I will call it, in the 1926 article 'Wat Wij Moeten Doen', or 'What We Have to Do' (Kentering, June). A good socialist needed to be an active member of the socialist youth movement, which implied regular attendance and putting the organization ahead of themselves. They also needed to have a well-founded understanding of socialism. Finally, they needed to be good at their work. Tinbergen continued by acknowledging that all this is a tough burden to bear:

"But is it even possible to approximate this ideal remotely? Is it humanely possible? It would seem to be so. Well, then we have to make decisions. First we have to lose all superfluous luggage! Here I touch on a sensitive topic: I have to denounce that many members of our organization are simultaneously occupied with other things, next to the socialist youth movement, blue movement,

> etcetera. Do not misunderstand me! We are not opponents of these other movements; but we do think, that the socialist movement is most important, that is why we are social democrats. This requires our entire person. More than that, but this we cannot give." (p. 119, my translation)

The good socialist, in other words, should direct his entire life according to the socialist cause. This conviction was not unique to Tinbergen. The members of the Arbeiders Jeugd Centrale ('Workers Youth Centre'), for example, were known for their insistence that socialism required reforming people as well (Naarden, 1989). What was special for Tinbergen was that the belief, that socialism needs to come first in a person's activities, raised questions about the tension within his own activities as a physicist-socialist. In search for advice on how to resolve this, he turned to Wibaut, a leading social democrat at the time:

> "To be precise I have taken doctoral exams in mathematics and physics, but do not believe I can be of great service to the socialist movement with those subjects. Since my professor is very much in favor of me continuing to study, I am now working at economics and statistics. I arrived at the decision to study those subjects because of the economic character of many socialist reforms and through the conviction that the socialist economies will need skilled people… With this training, will I be of use to the working class?" (Tinbergen 1926, cited from Boumans 1992).

Tinbergen, in other words, felt that a good socialist should aim all his activities at fostering the socialist cause. His academic work was no exception. As a result, he faced the challenge of reconciling Tinbergen the physicist and Tinbergen the socialist, and a turn to economics – mathematical economics, to be precise – was his answer. This does not mean that the move came easy to him. In April of 1927, Tinbergen wrote a letter to his old high school physics teacher, T. van Lohuijzen. While the contents of this letter have to be inferred from Van Lohuijzen's response (Letter from Van Lohuijzen to Tinbergen, 5th of April 1927,, Erasmus University Tinbergen Letters, 001L008), it is clear that Tinbergen told him that he was leaving physics and that he hoped Van Lohuijzen was not disappointed in him. Van Lohuijzen's response is warm and encouraging, and deserves to be quoted at length:

> "Before I see you in person, I want to respond to your letter in writing. That allows me to clarify what I feel on the matter. I am aware that, aside for your love for the sciences, you also carry great love for your fellow humans, and that you dedicated much of your time and energy to improving their circumstances. And I can understand so well that you looked for a synthesis! (…) That is why, instead of a feeling of disappointment, I am happy that you found a niche in which you study can use your study to the betterment of humanity."

That Van Lohuijzen calls Tinbergen's turn a 'synthesis' ("synthese" in the original Dutch) deserves particular emphasis, because the term synthesis will receive special attention in section 4. Van Lohuijzen continues by assuring Tinbergen that, despite his new orientation, his background in physics would never be lost.

"Never consider the past years of scientific study as lost. Your approach to problems and your ability solve problems have become so much broader and deeper because of it."

3.2.2. Technocracy

The remainder of this section will outline two ways in which Tinbergen tried to unify his academic and political persona. The first is Tinbergen's technocratic approach to societal problems; the second is his conviction that a scientific approach could offer a way out of political disagreement. Tinbergen's mentor, Paul Ehrenfest, was an influential factor in both.

One would not have been surprised if Ehrenfest had been a socialist himself. Ehrenfest himself said that his interest in economics stemmed mainly from his interest in the fate of the proletariat and his own background as a grocer's son[8] (Hollestelle 2011), and his willingness to lend his house for meetings of his many socialist-inclined students had earned him the nickname of the 'red professor' (Alberts 1994). But despite these sympathies, he was never the outspoken defender of any socialist doctrine. Ehrenfest and his wife Tatyana enjoyed attending the socialist student meetings, though Paul tended to disagree with much of what was said. In one such meeting, he stated "Jan, I simply cannot assume that all men are equal"[9].

Ehrenfest's political views are best described not as socialist, but technocratic (Hollestelle 2011). Technocrats believed that many societal issues were best approached as technical problems. The movement, which originated in the United States, had blown over to Europe since its inception in 1919. Technocratic ideals had found their most receptive audience in physicists and engineers, both in the United States and in the Netherlands. What separated the Dutch from the American reception was that technocratic ideas in the United States were pushed by civil society, while technocratic ideas in the Netherlands were mainly pushed by the political elite, and in particular socialist circles (Rodenburg 2014; Boumans 1989). In the academic centers of Leiden and Delft, this would give birth to a particular branch of socialism that Tinbergen would embody: 'ingenieurssocialisme' (engineer socialism). At the time Tinbergen wrote his dissertation with Ehrenfest, however, ingenieurssocialisme had not yet crystalized as a separate school of socialism. This underlines the innovative nature of their thinking on the intersection between technocratic and socialist ideals.

In his beliefs, Ehrenfest was particularly influenced by conversations with Jan Goudriaan, Philip Kohnstamm and the American physicist Lewis Tolman (Hollestelle 2011). Tolman was a member of the Technical Alliance that pushed for technocratic reform in the United States. Ehrenfest was also inspired by a book by H.G. Wells, 'The World of William Clissold', in which the protagonist pleads for scientifically backed reforms of society after losing faith in socialism.

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[8] Hollestelle (2011) reports that Ehrenfest wrote this to Schumpeter, ESC10:5, 3rd of May 1918.

[9] Cited in Alberts 1994 p. 282.

As a corollary of his particular technocratic beliefs, Ehrenfest believed the debate about the marginalism of the Austrian school and Marxism did not require an either/or verdict. Instead, he was interested in finding out how both were best combined. He was also interested in the work of Keynes, whose background in logic and philosophy appealed to Ehrenfest and whose advocacy of a more active role for the government shared characteristics with Ehrenfest's technocratic ideals. Despite his interest in the subject, Ehrenfest never publically defended his political views[10].

Tinbergen took over Ehrenfest's view that societal issues should be addressed as technical problems (Tinbergen 2013)[11]. This did not prevent the two from having definite ideological differences and different instruments of choice. With respect to the latter, it seems that Ehrenfest was more comfortable defending his political views within the university and its related spheres, while Tinbergen favored a more active approach. Ehrenfest never declared himself in favor of any particular ideology, while Tinbergen was a member of the SDAP and active in the socialist youth movement. The two agreed, however, that much could be gained by approaching the economy as if it were a mechanical system. By discovering the general tendencies to which the economy conformed, economic and political debates could transcend the ideological. The key to ameliorating the situation of the proletariat, with which both were concerned, lay not in heated debates between opposing philosophies. Instead, it should start with a careful study of the economy. The political sympathies of both thus encouraged an interest in this new way of looking at the economy.

The clearest example of Tinbergen's technocratic sympathies was the *Plan van de Arbeid* (Labor Plan) that he co-wrote with Hein Vos for the SDAP in 1935. The plan outlined how the Dutch economy could be organized by rational principles. Vos later defended the plan by explaining that the authors believed that society would benefit from scientific guidance (Hollestelle 2011). But Tinbergen's belief in the use of science for the organization of society, and in particular for the socialist cause, was already present in earlier writings.

In 'Verstand of Gevoel' (May 1924, published in Kentering), Tinbergen responded against criticism he had received for a speech that he had given at a socialist youth camp. In his speech, Tinbergen defended the relevance of science for the socialist cause. Critics had responded that socialism was best helped with "passion, hope and love" (p. 24). In this article, Tinbergen retorted that while passion, hope and love might dictate the aims of the socialist movement, they are not sufficient causes for its attainment. Science could help socialists on the road to socialization:

> "There will have to be passion and the willingness to sacrifice in addition to hope and love, to propagate socialism and increase its power. (…) But once we are convinced of our cause and have

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[10] Tatyana Ehrenfest, it might be worthwhile to add, did publish her views in a manifesto (1946).

[11] "The objective of scientific work should generally be, as I learned from my own physics teacher, P. Ehrenfest, to formulate differences of opinion in a "nobler" way than merely as conflicts." (p. 331).

> propagated our views; when we finally have to do what we have talked about for so long; then science will have to be our sword" (p. 24, my translation)

In order to forge the swords that socialists could wield, one needed competent blacksmiths. Tinbergen wanted socialist students to do their part, and founded a study committee in the SDSC ('Wetenschappelijk Sosialisties Werk', October 1927). This study committee had two aims: firstly, to study directly the means through which the socialist agenda was best carried out, and second, on a more reflective level, to contemplate which organization of science would best serve the socialist program. With organization I more specifically mean prioritization: Tinbergen suggested that some fields, which bore no or only a loose connection to socialism, should be discontinued, so that socialists could concentrate their limited manpower on those problems that were most pressing.

Tinbergen later explained that this need for prioritization did not only hold across disciplines, but also within economics. In 1929, Tinbergen published the article 'Vraagstukken van Socialistiese Ekonomie' ('Questions of Socialist Economics') under the pseudonym 'Jan Dirks'. This pseudonym probably derives from his father's first name, Dirk. In the article Tinbergen repeated his conviction that socialists needed science in order to transition to the socialist state, but now gave a more thorough account of why this is the case. According to Tinbergen, the structure of the economy had changed. In past times, the Dutch economy had approximated perfect competition. In such a setting, the self-interestedness of individual agents ensured a fair distribution for all. In Tinbergen's times, the situation was different: market power was increasingly concentrated in fewer parties, which dissolves the self-organizing properties of a perfectly competitive market. This distinction between 'perfect competition' and the concentration of market power echoes Cournot's views about imperfect competitions, of which Tinbergen was well aware.

According to Tinbergen, this change in economic structure meant that the self-interestedness of agents was no longer sufficient for a fair distribution. Additional principles were needed in order to ensure that the distribution of wealth was just. The search for these principles introduced new aspects into the economic science:

> "In general the setting of such principles – e.g. for taxation, the distribution of supply areas, the determination of wages – are not or only rarely counted as economics. This is because here a new term enters into play, namely "justice". People are used to banish such terms, which relate to "ethical considerations, from the economic science. It is in question whether this in time effective, because such considerations will increasingly influence and form the economic system. (…) The more economic equals organize themselves – in the form of unions, cooperation', trade organizations, trusts, etcetera - the more new principles are needed, in which considerations of justice play a role; together with a greater efficiency, the new concept of "justice" will be a necessary element of the economy." (p. 535, my translation)

This passage seems to suggest that Tinbergen' views on the relation between science and politics were evolving. Tinbergen's earlier distinction between 'science' and 'politics' was not so clinical and clean as it had been when he wrote 'Verstand of Gevoel' in May of 1924, as if political values set the agenda but the economic science itself was value-free. In 'Vraagstukken van Socialistiese Ekonomie', he made a different claim: political principles should play a significant role in economic policy. But the need for additional principles was not merely motivated by his socialist agenda; they were also necessary because the structure of the market has changed. As Tinbergen put it, our need for them "does not follow from a desire for being principled, but is a logical consequence of the new reorganizations that are slowly occurring in society" (1929, p. 540).

While Tinbergen's use of physics will be the subject of section 5.1.2, it is clear that Tinbergen's background in physics helped him to think about this topic. In a 1928 article on the structure of exchange ('Opmerkingen over Ruilteorie'), Tinbergen explained that the distribution of welfare over a society depends on the structure of the market. In order to attain a particular distribution of welfare, one had to specify additional constraints regarding the organization of exchange. Is this a perfectly competitive market? Or do we have few buyers and many sellers, or the other way around? Tinbergen likened this to the use of binding functions in physics, which constrain ranges of solutions in mechanics. More generally, both articles suggest that the outcomes of market interactions can be influenced by changing the boundary conditions. By doing this in the right way, a more desirable distribution of welfare might be attained within the confines of a capitalist system. As such, both articles contain traces of the thinking that Tinbergen would apply with Hein Vos in the Plan van de Arbeid.

Before moving on, it is interesting to consider why Tinbergen wrote 'Vraagstukken van Socialistiche Economie' under a pseudonym. The most obvious explanation is that this had to do the fact that Tinbergen worked at the Centraal Bureau voor de Statistiek (CBS) during the publication of this article.

On the one hand, this explanation is seemingly contradicted by the fact that Tinbergen published many articles under his own name during his period at CBS, both in de Socialistische Gids and elsewhere. The first, a two-part article on theories of exchange ('Opmerkingen over Ruilteorie' en 'Opmerkingen over Ruilteorie (slot)') had been an exposition on Edgeworth-Bowley boxes and an extension on the basis of Cournot. Both parts considered the structure of the economy and economic exchange. Later articles in the Socialistische Gids were a review of S. de Wolff's book on business cycles ('Economisch Getij', 1929) and an article on part-payment ('Kopen op Afbetaling', 1929).

On the other hand, these articles were all comparatively apolitical. Both parts of 'Opmerkingen over Ruilteorie' were largely explicatory, and both the book review and the article on part-payment were expository in tone. Jan Dirks' article, on the other hand, was visionary in nature. This was particularly the case because, as Tinbergen attests, serious economists preferred to take the view that ethical considerations had no place in economics. For that reason, the article may have been too political to be published under his own name.

3.2.3. Science and Conflict

Ehrenfest and Tinbergen's shared belief that different theories that pertain to the same phenomena do not necessarily contradict each other was also present in Tinbergen's early writings. In 'Wiskunde –

Grenswaarde - Marx', Tinbergen commended the ability to *combine* competing theories as one of the virtues of the mathematization of economics. While one theory might be considered the most accurate description of phenomena, another might in some situations be more useful due to its simplicity or its determinacy. The same facts can be described in different ways and with different assumptions, and for that reason the correctness of the conclusions should be the distinguishing factor.

Tinbergen illustrated this point with physical and economic examples. For the physical example, Tinbergen briefly referred to the familiar case of the astronomical application of Newton's classical mechanics and Einstein's relativity theory. While relativity theory was seen as the most accurate representation of planetary movement, Newton's classical mechanics – which is much simpler – would serve for most purposes. For the economic example, Tinbergen referred to the debate between the Austrian School ("with limit theory as their core values" (p. 67)) and Marxist economists. According to Tinbergen, the theories of the former tended to be "more correct" about general economic mechanisms, but were simultaneously often too complicated or too indeterminate for particular cases. Marxist theory, on the other hand, would often be too crude for general conclusions, but was true to many particular cases. Consider, for example, the labor market. Austrian School economics argued that workers have significant negotiating powers with regards to their employers: they could move somewhere else if they didn't like the working conditions, and so the price for labor would set at an equilibrium between what employers were willing to offer and what workers demanded. Marxist economics on the other hand, held that workers often simply had to put up with what they are offered, because unemployment and consequentially hunger was the only alternative they had. The different economic principles of these two important schools of theory led, in other words, to different conclusions. The use of 'mathematical economics' lay in its ability to explore the consequences of different assumptions about economic systems, and to detect contradictions between the assumptions that different theories postulate – skills in which "the socialist side should be seriously interested", according to Tinbergen (p. 68).

This conciliatory tone is also present in a 1927 article ('Werkloosheidsproblemen') in which Tinbergen reviewed a number of known causes of unemployment, with the particular aim of distinguishing where exactly bourgeois politicians and socialist disagree. According to Tinbergen, bourgeois politicians and socialists agreed that employment mediation, public investment and unemployment insurance could diminish unemployment or at least remediate some of its negative effects. But even if these measures were undertaken, there would still be a residue of unemployment as a consequence of oversupply of labor: 'permanent unemployment'. This permanent unemployment could in principle be countered with population policies (lowering population growth would lower the labor supply; Tinbergen remarked that attempts in this direction had been unsuccessful, and should be a last resort), technological development (which cannot be controlled) and, finally, by redistribution. It is on that last subject that bourgeois politicians and socialists were divided. Bourgeois politicians wanted to lower unemployment by lowering wages and thereby increasing demand, while socialists doubted that this would work: they saw permanent unemployment as a necessary implication of the capitalist system, in which the existence of unemployed labor served as an implicit threat for capitalist workers by reminding them that they were expendable. Socialists, on the other hand, pled for public investments and the reduction of the workweek, which would redistribute the ‘pain’ caused by unemployment over society as a whole. Tinbergen attempted to bring the two sides of the debate closer together by emphasizing the extent of their agreement. This shows that he was not interested in making political conflicts any larger than they needed to be.

3.3. Conclusion

Jan Tinbergen had clear ideas about the socialist state, but also clear ideas about the kind of socialist that would lead the country to it. This picture of the life of the good socialist asked a lot of others, but also of Tinbergen himself. The tension between Tinbergen’s education as a physicist and Tinbergen’s beliefs as a socialist troubled Tinbergen, as was evident from his communication with Wibaut. In his attempt to resolve it, Tinbergen took up a technocratic approach towards economic problems that he had learned, amongst others, from Paul Ehrenfest. Within this technocratic approach, Tinbergen applied styles of reasoning that he had learned in physics to the economic problems that socialists were concerned with. In addition, Tinbergen used that background to reconcile seemingly opposing sides of political debates.

4. A Physicist in a Changing University

This section will put Tinbergen's transition from physics to economics in the context of two kinds of developments in academic life. The first development is the changing role of the academic within Dutch society as universities and academics became more and more embedded into the broader society. Section 4.1 will show that this changing role followed from an increasing specialization among academics, the tendency towards public needs among universities and the competition that Hoogescholen posed for universities. The second development is the intellectual movement towards synthesis, which is characterized by the desire to overcome dichotomies within and across disciplines as well as between science, art and religion. Section 4.2 will show Tinbergen's involvement with synthetic thinking and the synthetic movement.

4.1. Tinbergen the Academic

4.1.1. Academia Evolves

Tinbergen's move from physics to economics took place in a time when the academy itself was in upheaval. A general account of a changing role and perception of Dutch universities and academics in this period is described by David Baneke in 'Synthetisch Denken' (2008). According to Baneke, natural scientists between 1900 and 1940 were struggling with the public duties of universities. Two important questions were whether natural scientists should serve public interest and, if so, how that could be done best. On the one hand, Dutch scientists were exceptionally successful: Lorentz, Kamerling Onnes and many others could be found at the forefront of many of the physical discoveries and innovations of the time. On the other hand, Baneke describes that there was an increasing concern about the specialization that was required to keep up with the rapid growth of individual fields. Scientists could only handle developments in their own field by foregoing developments in and connections with others. Scientists could, in other words, no longer reasonably aspire to be a *homo universalis*. As a result, natural scientists gradually lost their stature as 'public intellectuals', and universities lost their stature as the institution that delivered them.

Specialization was not the only force at play. For a long time, academics had had clear priorities: education was their first priority as ordained by the law, and research, their second priority, was guided by their personal scientific curiosity. Within the debate on the public position of academics, one of the dimensions was whether curiosity should indeed be so dominant, since both the public and the private sector were increasingly aware of the economic and societal potential of scientific innovation. This awareness had led to the founding of applied laboratories, such as the Dutch Institute for Applied Scientific Research (TNO) and Philip's NatLab. At the same time, research in the natural sciences was becoming more and more expensive by the year because the experimental setups became more complex and precious. The question how to fund these rising expenses became more and more acute. Despite these concerns, many academics rested in their belief that academic research should primarily be guided by scientific curiosity – but even they were sometimes compelled to venture into the private sector, for example by research fellowships or appointments as lecturer, in order to supplement their academic stipend.

Similarly, more and more academic graduates were pushed to jobs outside of the traditional domains of law, medicine, clergy and education. Instead, they often ended on new positions that appeared at the intersection of public, private and academic life. In many fields, natural scientists had to compete with engineers who had graduated from 'Technische Hoogeschoolen' (colleges of higher vocational education, specifically of the technical variety). While these Hoogescholen were traditionally distinct from universities, both in their public function and in the students they attracted and delivered, the difference was decreasing: Hoogescholen were broadening the education of their students in order to make them multifaceted, while universities were making their programs more practical to serve the needs of society.

The question arose whether academic were properly trained for jobs outside of the university; but, conversely, also whether society and in particular politics would not be better off with scientists in key positions. The term 'expert leadership' became important in that last context. Expert leadership was seen as a combination of knowledge, scientific thinking and a practical mindset that could organize processes more efficiently. Processes should be interpreted in a broad sense of the word: expert leadership was thought to benefit production processes in the private sector, but also the organization of the economy as a whole. Expert leadership was also seen as a way to resolve political discussions by technocrats.

The position of the scientist with in the Dutch society was, in brief, changing. This section will show two ways in which that new position – more embedded into society, less isolated in an intellectual ivory tower – manifested itself in Jan Tinbergen. Firstly, Tinbergen and Ehrenfest together speculated about organizing a new educational program for future economists. Secondly, Tinbergen's work at the Central Bureau for Statistics was an example of an academic in an applied position.

4.1.2. An Education in Economics

In his work on Ehrenfest, Hollestelle (2011) points out that an important motivation for Ehrenfest's interest in economics was his desire to make universities more relevant to society. According to Ehrenfest, universities risked alienating themselves from society by their indifference towards social issues. In order to remain relevant, the university should adapt. This section will show that this motivated him to contemplate instigating a new program for the education of economics, together with Jan Tinbergen.

Ehrenfest held particular beliefs on the relation between pure and applied science. While he was himself schooled in pure theory, Ehrenfest was not unfamiliar with practical problems due to his early introduction to them by his brother Arthur. This early acquaintance was renewed through Ehrenfest's involvement with Philip's Natuurkundig Laboratorium (Physics Laboratory), or NatLab, in Eindhoven in 1920 (Hollestelle 2011). NatLab had been founded in 1914 after the example of General Electrics, and was headed by the Leiden-trained physicist Gilles Holst. Its main aim was to aid the development of Philips product through Philips-owned patents. The Netherlands had, after all, introduced its own patent laws in 1910, preventing Philips from using technologies that were patented elsewhere. Working at NatLab and similar institutions often paid much better than university positions, though they were usually not esteemed as highly. The NatLab colloquia were organized to keep the engineers who worked there up to date with the latest developments. Ehrenfest's credentials as a professor in Leiden and, more specifically, as a gifted speaker with the talent to make complicated matters clearly understandable, made him a perfect candidate for lectures at NatLab. For Ehrenfest, the prospect of alleviating some of the financial troubles which had plagued the Ehrenfest's from the beginning of their period in Leiden probably formed part of the reason for Ehrenfest's interest in an affiliation with NatLab. In addition, his lectures on theoretical physics to the generally practice-oriented audience[12] at NatLab fit in with Ehrenfest's broader educational philosophy. Ehrenfest was of the opinion that physics could only be applied to practice once a solid education in pure physics had been completed. This was translated into practice in 1929, when Ehrenfest arranged a new chair for industrial physics in Leiden. Again upon Ehrenfest's request, it was first occupied by Holst.

Ehrenfest was confronted with alternative views during two visits to the United States (Van Lunteren & Hollestelle 2013). Ehrenfest was first invited to the US by Robert Milikan, who invited him to the California Institute of Technology (CalTech) in 1923. Ehrenfest accepted because he wanted to arrange contacts between American and Dutch physicists. The second trip was in 1930, when Ehrenfest visited Charles Kettering, an inventor and the vice-president of the research division of General Motors. During his stay, Ehrenfest was struck by the pragmatic orientation of American scientists. On the one hand, Ehrenfest was dismayed that, to American physicists, the social use of physical research appeared more important than pure research. Ehrenfest intended to remind them of the importance of the latter. On the other hand, Ehrenfest was impressed with the attention for career opportunities outside of the academy: students were informed of possibilities in engineering in regular lectures, one of which Ehrenfest attended. Similarly, Ehrenfest noticed that strong social ties came with a significant financial backing. More than half of university budgets consisted of private, rather than public, funds (Hollestelle 2011).

This dual attitude towards the American pragmatic orientation fits in with the view that Ehrenfest welcomed the practical application of physics, but only after a solid pure physical basis had been laid. Ehrenfest's work at NatLab and his travels to the United States made him aware of the opportunities that came with tending to social needs, but also reinforced his belief that scientists could only cater to social interests once they had been properly trained in a pure science. Part of his inspiration came from the American educator Flexner, who held that a prominent place for public interest in universities would lead to declining academic standards. Ehrenfest met Flexner during his second trip in the US and, to some extent, shared that concern. At the same time, he saw the benefits of social embeddedness of the university: the virtues of education of innovation aside, the university as an institution could profit from public support for the financial needs of universities. Given the prospect of

[12] Holst wanted NatLab to occupy itself with both pure and applied science. Gustaf Hertz and his work on gas discharges are an example (Hollestelle 2011, p. 187). Nonetheless, NatLab's emphasis was on practical applications.

increasing costs and competition, mainly from the United States, Ehrenfest saw the task of securing funds for the future as an important challenge.

In the face of these concerns, Ehrenfest was troubled by the fact that universities, as institutions, had been largely indifferent to social changes. Applied physics was not a part of the university, and agricultural sciences, veterinary sciences and economics were never considered for inclusion. The development of an education in economics, specifically, was still in its earliest phases. The only courses available were in political economics – the kind of economics that addresses the proper maintenance of the state – which was taught as an optional course to law students. The same was the case for statistics. These courses were insufficiently available, and their content insufficiently applicable, to meet the needs of an increasingly complex private sector. This motivated the private sector in Rotterdam to found the 'Nederlandse Handels-Hoogeschool' (Dutch School for Business), or NHH, in 1913 (Wilts, 1997). The example was soon followed by the University of Amsterdam, which added a faculty of business administration in 1921, and Tilburg, which founded the RK Handels-Hoogeschool (Roman Catholic School of Business) in 1927. These developments reinforced the idea that law school was an inadequate basis for the kind of economics that was appropriate for the modern world.

Economics education in the Netherlands was, in other words, on the move. This may be why Paul Ehrenfest and Jan Tinbergen, after the latter's successful move from physics to economics, speculated extensively about the idea of founding a new economic education on a physical-mathematical basis (Hollestelle 2011). This idea combined Ehrenfest's desire to make the university relevant to societal interests, but also matched his conviction that science could only successfully be applied after a pure education was completed. In addition, it chimed well with the shared conviction (which will be the subject of section 3.2.2) that some problems in society are best approached as technical problems that can be solved with technical instruments. Ehrenfest and Tinbergen speculated on the matter in 1929 and 1930. Ehrenfest was first to float the idea (ESC9:406, Letter from Ehrenfest to Tinbergen, 20th of March 1929). Ehrenfest starts by suggesting that Tinbergen could teach students at the physics faculty in Leiden, who are similarly gifted and disposed towards the same worldview. But he also discussed the possibility of a "coordinated partnership" that, within two or three years, should be able to reach 500 students with "an intensive social interest and sense of responsibility, mathematical aptitude and a clear awareness of for the new aims of schooling and work". Ehrenfest believed that efforts in this direction would be valuable to the Netherlands, but also to economics in general. In a particularly venomous remark, Ehrenfest remarks that Tinbergen should keep in mind "how bad even Bowley is, and how enormously the world needs people of the Keynes-type".

It is Tinbergen who returns to the topic in February of the next year (ESC10:2, Letter from Tinbergen to Ehrenfest, February 16th 1930). During his work at the CBS, Tinbergen felt that the need for people with an appropriate background in economics and statistics was increasing. An education into this field should at least cover the following subjects:

a. "Theoretical (mathematical) economics, as you have taught it to me and in which amongst others the following books could be recommendable: Bowley, Wicksell, Pareto (briefly), Barone and perhaps Roos' articles; probably also the new book by H. L. Moore (with which I am not familiar yet)

b. Probability theory and error theory, and correlation theory.
c. Literary economics, amongst others something about business cycles.
d. State of the art and methods of quantitative research. Mitchell, Wagemann for books, and otherwise mainly journals." (my translation)

Tinbergen proposes that Ehrenfest take care of the second course, while he would do the fourth and the first could be shared. Literary economics could be taught by an external teacher.

Tinbergen closes his exposition on the topic by acknowledging that he doesn't know how Ehrenfest feels at about the initiative at this point, and that much will depend on his health. Indeed, Ehrenfest's depression was sapping his energy, and Tinbergen accepted a teaching position in Amsterdam in 1931. The plan for a physical-mathematical economics education was, consequently, never put in practice. It is nonetheless clear that Ehrenfest and Tinbergen's shared interest in an academic economic education resonates with the broader sentiment described by Baneke, according to which natural scientists were increasingly looking for new ways to become relevant to society.

4.1.3. Tinbergen at the CBS

Baneke also points out that natural scientists increasingly fulfilled positions outside of academia. Ehrenfest's activities at NatLab are a good example. Tinbergen, too, showed a willingness to roll up his sleeves and work outside of the ivory tower of the academy. This was compatible with his view of scientific work, according to which one should not merely be motivated by personal interest:

> "It is definitely the case that science is a means [of satisfying personal interest] and as such she is of high value; but for those who work in science it should not be – that is, it should not be the only reason." ('Wetenschappelijk Sosialisties Werk', 1927, p. 5)

In his early years, this mainly manifested itself in his work at the CBS, where he was active since August of 1927. Tinbergen arrived in an institution that was actively searching for its position within Dutch public life, having both grown and shrunk during the ten years before he joined (Idenburg 1952). The institute had rapidly gained importance during World War I, when the turmoil that surrounded the Netherlands had a drastic impact on economic life. While it was clear that particular goods had become scarce and that prices were rising, the Dutch government had insufficient information to provide an effective response. The CBS, which had been of limited importance until then, was charged with improving the information position of the government. It is noteworthy that the SDSC played an important role in data gathering during the war: the youth organization collected data on the cost of living of working families in Amsterdam.

This connection to the war meant that the CBS was faced with a shrinking budget once the war was over and all 'war institutions' were resolved. These cuts had a severe impact on the range of statistics that the CBS could provide. The project on which Tinbergen worked during his period at the CBS, which focused on the comparison of cyclical patterns in different economic variables, was a way for the institute to reinvent itself.

Tinbergen had been working for the CBS since August of 1927, as the second tier of his 18-month social service. This social service replaced Tinbergen's military service, to which he had successfully objected on grounds of conscience[13].

In his first publication on business cycles, 'On the Mathematical-Statistical Methods of Business Cycle Research'[14] (November 1927), Tinbergen aimed to relay recent developments in business cycle research as it was carried out by amongst others Bullock, Persons and Crum at the Harvard Economic Service. In business cycle research, Tinbergen explained, economists try to discover relations between different economic variables that tend to show cycles with similar periods. He explained that statistical methods were essential to this endeavor, and draws on an analogy with physics for illustration:

> "a large part of inductive quantitative research in economics will have to be carried out in this way, since unlike in physics one cannot experiment in economics; different states which can be compared only occur over the course of time." (p. 712, my translation)

In order to compare the changing values of different economic values, economists constructed so-called economic series, where an economic series is a set of data points of a particular economic variable at different points in time. In order to compare different economic series, which is necessary in order to find relationships between them, economists deduced standard deviations: the difference between the actual value of one particular data point and the mean of all different points. Tinbergen acknowledged that it is possible to decompose these standard deviations into different underlying trends, e.g. seasonal and secular trends, but did not discuss the issue at length. On the basis of standard deviations, economists could construct a correlation coefficient by multiplying the standard deviations of the different series and taking the average.

A complication was introduced by presence of 'lag' between economic series: i.e. that one series is not immediately be correlated with another, but with a particular delay. Tinbergen pointed out that while these lags were usually considered to be a fixed amount of time (e.g. a particular number of months), it was also possible to conceive of them as dynamical:

> "An economic dynamics could be constructed base on the [lag] relation between economic quantities, that results in the derivation of perfect cyclic oscillations of an economic system. This is the mathematical interpretation of Aftalion's crisis theory. (...) I mention this theory in

[13] Tinbergen had already worked in a prison from May of 1926 to August of 1927 (Jolink 2003).

[14] 'Over de mathematies-statistiese methoden van konjunktuur-onderzoek'

particular because it explains most clearly how the elations considered here can happen, in that every cycle already contains the seed for the next cycle and thus real periodicity occurs." (p. 715 and note, translation due to Marcel Boumans 1992 (p. 24))

Tinbergen did not mention the mechanism with which Aftalion explains business cycles[15], other than to note that it explains cyclical fluctuations in terms of the cycle itself. The distinction between this kind of explanation and an explanation in terms of lags will be discussed in section 5.1.3.

The article closed with a number of comments regarding the relation between correlation and causality and on the status of correlations that were deduced from accumulated series. These were among the most critical remarks in an otherwise mainly expository article, because Tinbergen pointed out a number of shortcomings in the way Harvard economists used accumulated series. Boumans points out that Tinbergen even tried to get his article published in the *Journal of the American Statistical Association.* The article was rejected because it had already been published in *De Economist* and because the editors felt that Tinbergen mistakenly attributed to Bullock, Persons and Crum the view that accumulated series were of no use to business cycle research, while they in fact only pleaded for caution (Boumans 1992, p. 23).

Tinbergen's work at the CBS showed that he, like many other scientists, was looking for a way in which he could contribute to society. Tinbergen worked at the CBS until around the time he finished his dissertation in 1929, but returned to the CBS in July.

Things could have been very different: Tinbergen had been close to accepting a position at NatLab. It was perhaps due to Ehrenfest that Tinbergen visited Goudriaan, who headed NatLab, to inquire after a position for himself. In a letter to Ehrenfest, Tinbergen reports his visit with some disappointment (ESC9: 389, Letter from Tinbergen to Ehrenfest, 23rd of December 1928). Tinbergen was interested in the field in which a position had opened: whoever filled the position would do research into adapting production curves to sales curves, in order to make production processes comply with demand. Unfortunately, Tinbergen had gotten the impression that Goudriaan would prefer a Hoogeschool-graduated engineer over academic like himself. As it turned out, Goudriaan did not consider Tinbergen unsuitable. Three months after this first letter, Tinbergen wrote Ehrenfest to report that Goudriaan had offered him a similar position (ESC9: 405, Letter from Tinbergen to Ehrenfest, 20th of March 1929). But by this point Tinbergen had a dilemma: he had already accepted a position at the Institute International de Statistique from April to July, and had promised to return to theCBS from July onwards. He summarizes the matter as follows:

[15] As Boumans (1992) points out, Aftalion's theory of economic cycles attributes cyclical fluctuations in economic series to the long period required to "the long period required for the production of fixed capital" (Aftalion 1927, p. 165, cited from Boumans). It is, in other words, "a consequence of the long delay which often separates the moment when production of goods is decided upon and a forecast is made from the moment when the manufacture is terminated, and the forecast is replaced by reality" (Aftalion 1927, p. 165, cited from Boumans).

"As a result I have to weigh the following factors:

1. It is of great importance to learn at Philips
2. If business cycle research does not receive an impulse at the CBS, it is a lost cause for that institute, which I very much care about.
3. In the transition from one "employer" to the other, I want to proceed by some moral principle, e.g. through consultation; not by the harsh method of competition." (my translation)

I have deferred all other factors, as being of a second order. I conclude that I cannot accept the position in Eindhoven this year. Originally I wanted to go to mr. Methorst, but I know what he would say, namely that they are counting on me – there are already things waiting since last year – and that I would harm them severely by not coming"

This letter strongly suggests that Tinbergen may actually have preferred to work at NatLab, but that he wanted to stay true to the commitment he had already made. Both his work at the CBS and his interest in joining NatLab show that Tinbergen was interested in applying his academic knowledge outside of the university walls, in line with the general tendency described by Baneke.

4.2. Synthesis

4.2.1. Synthetic Thinking

The previous section explained that the position of natural scientists was changing because of specialization, competition, progress and the opportunity costs they came with. This section will treat a parallel, philosophical development about the aims of science.

Around the turn of the 19th century, the reigning picture of the scientist and of scientific work had stated that scientists were levelheaded, hardworking wielders of the rigorous scientific method (Baneke 2008). Traits like creativity and imaginative power had no place in this description. While this reputation of scientists made them widely respected within Dutch society, it led to criticism elsewhere. Scientists were seen as cold and detached from society in France and Germany, where positivism had become the scapegoat of a perceived tendency towards superficiality and barrenness. This culminated in an 1895 article by the French publicist Ferdinand Brunetière. Inspired by an audience with Pope Leo XIII, Brunetière had become convinced that science had proven incapable to fulfill its promise to answer important questions about the destiny of humanity, the foundations of morality and the nature of behavior. Science had outspent its credit, and should be proclaimed 'bankrupt'.

While the debate about the bankruptcy of the science was not as lively in the Netherlands as it was elsewhere, it certainly had its repercussions. Even many natural scientists could sympathize with Brunetière's criticism, even though they did not agree that the net value of the natural sciences was negative. According to Baneke, the philosophical response came in the form of a widely shared plea for 'synthesis'. The search for synthesis contained a number of aspects. First and foremost, it was a search for unity behind different aspects of life that scientists usually saw apart: "Everybody sought for a synthesis, an all-encompassing philosophical system that combined science, art, religion, the human spirit and a political ideology." (Baneke 2008, p. 134). Synthetic thinking therefore constituted the desire to cross apparent boundaries within and across disciplines. But it also wanted to show the searching human behind the scientist. They resisted the idea that scientists work by applying the same instruments over and over again, much like a lumberjack fells a tree with his axe. Scientists were people too, each with his (and occasionally her) own style, approach and creativity. This is illustrated well by a 1934 speech of the physicist H.A. Kramers, who opened his speech on 'physics and physicists' with a famous physicist who had been renowned for his creative and authentic style, and who had unfortunately recently passed away: Paul Ehrenfest.

4.2.2. Tinbergen's Work on Synthetic Themes

Synthetic thinking was also present within economic thought. This is described by Groeneveld (1952) in his study of economic thought during the interbellum. Groeneveld's explains that synthetic thinking helped economists to overcome a number of longstanding oppositions in economic theory. My argument in this subsection will be that Tinbergen's work was closely intertwined with overcoming some of these oppositions, and that his work is therefore exemplary of synthetic thinking. While Groeneveld discusses a wide range of such oppositions, this subsection will restrict itself to three: an opposition about economic methodology known as the Methodenstreit, an opposition about business cycles and an opposition about economic order.

The original exchange on methods between the Austrian School and the Historical School is known as the Methodenstreit, and revolved around the proper nature of economic theory. The Austrian School of, among others, Carl Menger argued that economic theory should be deduced from universally valid premises, so as to arrive at universally valid theories. The Historical School of, among others, Gustav von Schmoller, believed that economic theories should consider events in isolation. Because every economic event has its own peculiar context, one could not arrive at universally valid theories. According to Groeneveld, economists in the interbellum pursued a synthesis between the two schools, in which hypothesis (in the style of the Austrian School) were confronted with evidence for individual situations (in the style of the Historical School).

For Tinbergen, this methodological synthesis was closely intertwined with his particular approach to resolving a second opposition: that between static and dynamic theories of business cycles. Static theory of business cycles, Groeneveld explains, tried to explain economic prosperity and downturns by comparing different individual states of the economy. This approach was justified by the assumption that markets tend to equilibrium, and that this movement towards equilibrium occurs so quickly that the process of change is comparatively irrelevant. Purely dynamic theories of business cycles did not compare individual states of the economy, but the change that occurs between them. This approach rested on the silent assumption that the movement of markets towards equilibrium is slower, if present at all. These differences do not mean that the two approaches cannot be brought together:

> "Insight in the causes [of business cycles] is currently being improved and clarified along two routes. The first route is that of building a scientific synthesis across those theories, which appear to diverge but in reality converge. The other is that of the statistical verification of business cycle theories, through which one can attain a deeper insight of the causal-functional development of business cycles. In this context it is among others the pioneering work of Prof. Tinbergen that is of the utmost importance, both for the theoretical conception and for its insight in the truthfulness." (p. 76, my translation)

Considered in this light, Tinbergen's attempt to dynamize otherwise static models was exemplary of both methodological synthesis and synthesis with regards to business cycle theories. Tinbergen's bridge between dynamic and static theories, after all, took the form of comparing abstract, dynamic hypotheses with empirical, static facts. While this becomes more explicit in Tinbergen's later works, some of his early works contained elements of this method as well. 'Over de Mathematies-Statistiese Methoden voor Konjunktuuronderzoek' (1927) was one example, because it combines the suggestion of dynamization with an emphasis empirical testing. Another early example is Tinbergen's 1928 work on Cournot, where he showed how *dynamic* effects could follow from *static* entry data, even though the entry data with which he is concerned at this point is, as we will see, hypothetical ('Opmerkingen over Ruilteorie (slot)'). This work will be discussed more extensively in 5.1.3.

A separate instance of an opposition that was overcome during the interbellum was that of economic order: the dichotomy between 'free market' and 'state planning'. After World War I, economic life was largely governed by free exchange. Government involvement was largely limited to a number of labor laws and some limited forms of social security, starting with 'het Kinderwetje van Van Houten' that prohibited labor for children under 12 in 1874 (Van Houten's Children's Law) (Dullaart 1984). This started to change in the twenties and thirties, when governments started to guide the price mechanism with the opposition of constraints. We have seen in section 3.2.2 that Tinbergen advocated this development in 1928 and 1929 (respectively 'Opmerkingen over Ruilteorie' and 'Vraagstukken van Socialistiese Ekonomie'), when he showed that market outcomes could be influenced by changing the boundary conditions so that the more radical rejection of the capitalist system may be superfluous.

4.2.3. Tinbergen's Work with the Synthetic Movement

The previous subsection showed that Tinbergen worked on topics that were exemplary of synthetic thinking in economics. Tinbergen can also be linked to the synthetic movement more directly through his cooperation on the 'Encyclopaedisch Handboek voor het Moderne Denken' ('Encyclopedic Handbook to Modern Thinking') in 1931. Baneke (2008) points out that this Handbook, a two-part volume edited by A.C. Elsbach, H.T. De Graaf, H.J. Jordan and K.F. Proost, was one of the products of the synthetic movement.

Contrary to a conventional encyclopedia, the Handbook did not treat individual thinkers – it treated individual ideas. The synthetic ambitions of the group behind the Handbook were evident from the preface. The editors state that they aim for a wide audience that included "representatives of one or the other art, science or religion and those who train to become such a representative", because:

> "For the true development of the individual, science and civilization it is often unavoidable, yes, even necessary, that one exceeds the boundaries of one's profession. We count on readers and users, who are compelled to know what they say and do – who want to be held accountable and to learn from their mistaken. (…) The editors work together continuously, so the book will have a synthetic reach. We see modern thinking as a whole, even if humans are only rarely aware of that hole-ness, or even never completely" (p. viii, my translation)

Tinbergen wrote five comparatively large entries for the second volume of the Handbook, on topics within and outside of economics. His articles were on 'the organization of society' ('Organisatie – Maatschappelijke'), 'statistics', 'theories of value', 'capital & capitalism' and 'the application of mathematical methods in economics'. The last article, in particular, shows that Tinbergen's approach to the use of mathematic had changed little since 1925, when he published 'Mathematics – Limit – Marx'. Just like in that article, Tinbergen's article for the Handbook emphasized the distinction between the mathematical tools and the domain to which they are applied: "Mathematics merely plays the role of an auxiliary science, so it has no influence on the axioms from which one wants to continue or the particular causal complexes that one intends to consider" (p. 586, my translation). And again like the 1925 article, Tinbergen pointed out that mathematics can offer a faster path to solution to which one could only with great difficulty arrive through non-mathematical means: "the theories of every school can in principle be represented in mathematical or non-mathematical form. (…) One can only solve [problems] *correctly*, *incorrectly* or *not at all;* the use of mathematics is only a matter of taking more or less time to get there." (p. 586, original emphasis, my translation).

If there is any difference between the 1925 and 1931 articles, it is that the 1931 article put more emphasis on the existence of problems that were unsolvable without the aid of mathematics. This category largely contained problems with a large number of variables and dependencies, such as when one considers many markets simultaneously or when one generalizes over large sets of data. Tinbergen closed the article with the prediction that the more recent uses of statistics could provide mathematical economics with momentum:

> "In its first 75 years (one conventionally starts in 1838, the year of publication of Cournot's "Recherches"), mathematical economics has almost exclusively considered theoretical problems and concerned itself very little with statistical observations. This is a potential explanation for its relatively slow increase in influence. Recently, the desire has been gaining ground to make this [statistical] connection, which has proven so successful for the exact sciences, in economics as well, and a number of attempt in that direction have already been made. One can expect a flourishing of this discipline as a result of the developments in this direction; the analysis of

economic cycles, in particular, will reap the fruits of this, and can be helped by the study of business" (p. 589, my translation)

In addition to being published in a product of the synthetic movement, this article shows Tinbergen's affinity with synthetic thinking in the far-reaching role it attributes to mathematics. Tinbergen's views on the use of mathematics share the synthetic movement's emphasis on unity across disciplines by postulating mathematics as a neutral language in which the subject matters of different disciplines can, each in their own way, be discussed. Many disciplines could, in their own way, be described by mathematics; the mathematization of a discipline, *when carried out carefully*, should have no influence on the theories that are being tested. Underlying this role for mathematics was the belief that the relation between all things is mathematical. The belief that the language of mathematics can be used to describe these different domains – albeit under restrictions – coincided with the synthetic movement's striving for unity across disciplines.

4.3. Conclusion

This section has put Tinbergen's move from physics to economics in the context of the developing role of the academic. Ehrenfest and Tinbergen's joint plan for an economic education fits into the turmoil of the changing relation between university and society. In addition, Ehrenfest and Tinbergen each in their own way contributed to society from positions that were new for scientists. I have argued that some of the topics on which Tinbergen worked were typical for synthetic thinking in economic thought and that he actively contributed towards the synthetic movement.

5. A Physicist in Economics

The previous two sections have shown how Tinbergen's move from physics to economics can be understood in the context of his political beliefs and the changing role of the academic. This section will show how Tinbergen used his physical background in his economic work. The first part (5.1) will offer evidence that Tinbergen indeed did use his physical background. It will cover four 'case studies' – some brief, some more extensive – of topics and articles in which Tinbergen related tools from physics to economic problems. The second part (5.2) will reflect on his use of physical concepts and methods, and argue that two significant differences between Ehrenfest and Tinbergen's use of analogies have so far been overlooked.

5.1. Tinbergen's Use of Physics in Economics

5.1.1. Exchange

The first example will be constituted by Tinbergen's writings on exchange. Exchange was a returning topic in his early writings, which would lay the groundwork for his later work on planning. In order to show the development in his thought, and because it was a rare occasion on which Ehrenfest and Tinbergen worked together on an economic problem, this subsection will focus on two sources on the topic of exchange. The articles are linked by Tinbergen's use of the Edgeworth-Bowley Box[16].

Our starting point is a letter from Ehrenfest to Tinbergen in November 1925, on the topic of Pareto optimality. Jolink (2003) traces this topic to a letter from Ehrenfest to Tinbergen in November of 1925, so it is presumably around that period that we should localize the five-page handwritten note on which Tinbergen expands his thoughts.

In welfare economics, a distribution is Pareto optimal if no other distribution could make an individual actor better off without making any of the other actors worse off. Correspondingly, a Pareto improvement is a redistribution of goods that makes one or more actor better off without disadvantaging any of the others. An important issue in this context is that it is difficult to determine when that is indeed the case. The core problem lies with the 'interpersonal comparability of utility' – the fact that an external observer cannot directly observe the utility or disutility that someone else derives through consumption.

Tinbergen had already touched upon the interpersonal comparability of utility in a publication in Kentering in May of 1925. Tinbergen had reviewed an article that Karl Polanyi had written in the periodical of the Austrian sister-organization of the SDSC. In 'Neue Erwägungen zu unserer Theorie und

[16] A third article on the Edgeworth-Bowley box would appear in 'Mensch & Maatschappij' ('Person & Society') in 1930. That article is largely expository and combines elements from the first and the second article. While Tinbergen thanks Ehrenfest for his help in forming his thoughts on the topic, the article does not extend beyond the articles mentioned here. For that reason it will not be treated independently.

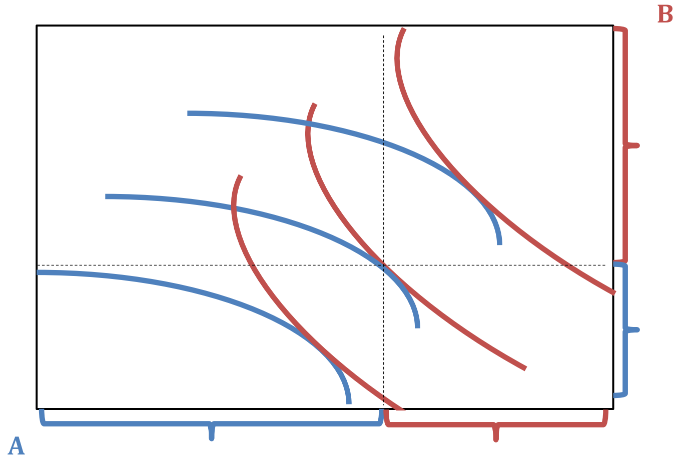
Praxis', Polanyi had argued that a socialist government required two distinct kinds of oversight in order to effectively govern a socialist state. The first kind of oversight is 'external' (Polanyi: 'äussere'. Tinbergen: 'uitwendig') oversight, which covers externally verifiable information (e.g. the quantity of supplies in stock and the amount of products produced by a particular production process) that is provided by statistics. The second kind of oversight is 'internal' (Polanyi: 'innere'. Tinbergen: 'inwendig') oversight, which factors that cannot so easily be verified. Polanyi had argued that statistics could not provide us with 'internal' oversight, but that deliberative processes within labor organizations could. Tinbergen disagreed on principle: internal oversight is impossible to attain because it is impossible to compare utility (or disutility: Tinbergen uses the example of hunger) between individuals.

In their notes, Ehrenfest and Tinbergen tried to circumvent the problem of the interpersonal comparability of utility[17] by slightly reformulating the conditions for Pareto optimality. They considered a situation with an *n* number of individuals, whose welfare is determined by the consumption of only two goods, x and y. The preferences of these individuals are expressed by indifference curves within an Edgeworth-Bowley box. I will explain both in turn.

Indifference curve are classical instruments of modern economics. If we assume that we know how much enjoyment we derive from the consumption of the first, second and n-th unit of x and y, an indifference curve is a curve connecting the points for which the total utility derived from consuming x and y is equal. It may be imagined, for example, that I derive the same enjoyment from consuming five units of consumption, achieved through labor, and five units of leisure, as I would from consuming eight units of consumption and two units of leisure, or from three units of consumption and nine units of leisure. Similarly, another indifference curve might connect the consumption of ten units of consumption and ten units of leisure; sixteen unites of consumption and four units of leisure and six units of consumption and eighteen units of leisure. For most goods, indifference curves reflect that most goods have 'diminishing marginal returns'. This means that the 'marginal utility', or enjoyment-per-extra-unit decreases as we consume more of it. This can easily be imagined: the utility of an extra unit of consumption will decrease as I consume more. That marginal utility decreases with quantity is called 'diminishing marginal returns'.

Edgeworth-Boxley boxes are graphs in which multiple – two, in simple cases – indifference curves can be brought together in order to represent different distributions of goods across agents. In the example in Figure 3, two actors A and B each have a number of indifference curves over the goods X and Y. Each point at which the indifference curves of A and B touch marks a Pareto optimal point. At such a point, exchanging one unit of X for one unit of Y would make either or both actors worse off. The final distribution of goods in this example is underdetermined by the indifference curves alone, and will depend on the initial endowment of both actors. If A starts with a significantly higher endowment than B, the final distribution will be closer to the highest blue indifference curve.

[17] Tinbergen used the term of 'ophelimity' rather than 'utility'. In the context of Pareto's welfare economics, ophelimity refers to enjoyment derived from economic sources, whereas utility refers to enjoyment derived from any source (Tarascio, 1969). I stick with 'utility' here and elsewhere to facilitate the explanation.



Edgeworth-Bowley box

Figure 3

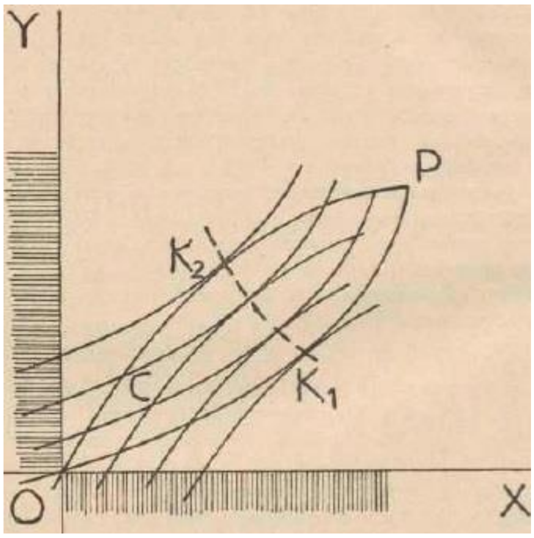
In Ehrenfest and Tinbergen's example, all *n* individuals were represented with indifference curves over the goods X and Y. Ehrenfest and Tinbergen then asked under which conditions the distribution of X and Y over the individuals 1 to n would be considered fair. In order to take into account that different people might have different beliefs about fairness, they rephrased the question slightly to arrive at their own version of Pareto optimality: given what distribution of X and Y would no one want to swap places with someone else? Under their phrasing of the problem, the criterion for Pareto improvement is changed from its classical formulation, as the improvement of the utility of some actors while the utility of others remains unchanged, to the willingness of individuals to change places. Ehrenfest and Tinbergen thereby avoided the usual problems of the interpersonal comparison of utility.

The Edgeworth-Bowley box re-appears in an article that Tinbergen wrote for de Socialistische Gids in 1928, albeit in a different context: where the 1925 article considers welfare, the 1928 article considers exchange. This distinction is relevant for three reasons. Firstly, the role of price is more prominent in an exchange setting than in a welfare setting. Secondly, the 'thing exchanged' was different in both cases: in the 1925 article, Tinbergen and Ehrenfest considered whether it was beneficial for *two individuals* to switch places; in the 1928-article Tinbergen considered whether it was beneficial for *two goods* to be exchanged. What the welfare-example and exchange-example have in common is, however, that the final distribution is in both cases underdetermined by the indifference curves (Figure 4, p. 432). In the case of exchange, Tinbergen argued that additional constraint is the 'organization of exchange'.

Tinbergen considered two ways in which trade can be 'organized' so as to render the answer determinate. In the first case (Figure 5, p. 435) A and B have the same bargaining power; both can determine the quantity they wish to exchange at a given price. Consider first what would happen if the price was given by line OR in figure 5. At that price, OR touches the indifference curves of A and B, which are denoted by U_A and U_B, at different points. This reflects that OR would force both parties to have more of one good and less of the other good than would be optimal given their preferences. In order to attain this optimal distribution, A and B will bargain until the price has become OQ. OQ touches U_A and U_B at the same point, with the equilibrium quantities of x and y at K. This is one way to attain a determinate answer.

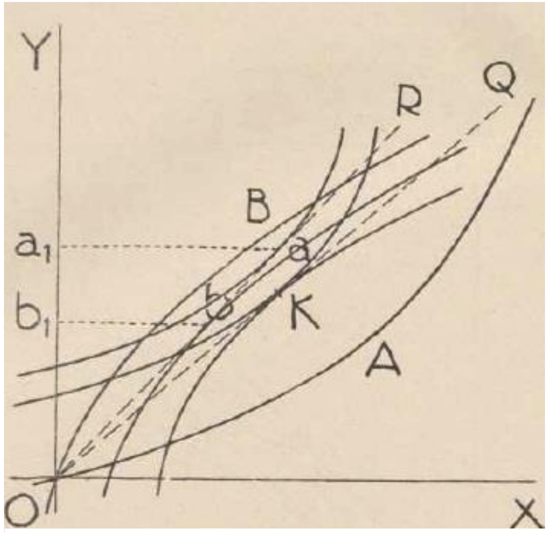
In the second case, the organization was different. In the first organization, the equilibrium price and distribution arose through bargaining of the two individuals. In the second organization, one individual sets the price while the other determines the quantity exchanged (Figure 6, p. 436). If the curves U_A and U_B are known, and A sets the price, then A knows which quantity B will buy given a particular price, viz. the quantities found at the points at which the line representing price is tangent to U_B. Under those assumptions A will set the price so that his own utility will be highest (point L in Figure 6).

The choice for a particular way of organizing exchange has important consequences for the resulting distribution of goods. Here we arrive at the way in which Tinbergen made use of his background in physics: Tinbergen believed that this function of the organization of trade, i.e. the choice for whether the first, second or any other organization applies, is similar to the function of binding in mechanics:



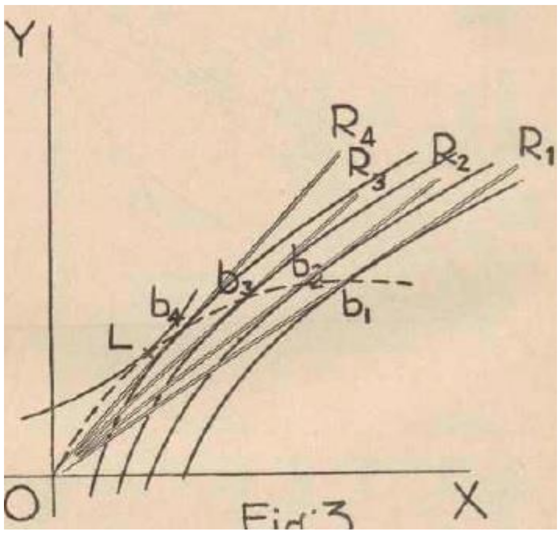
Preferences underdetermine distribution

Figure 4



Equal bargaining power

Figure 5



Unequal bargaining power

Figure 6

> “In these “organizations” or “forms” of exchange, which are set in advance and are comparable to binding equations in mechanics, lies the possibility of the solutions that have been given” (p. 437-438, my translation).

This analogy rests on the fact that physics, too, has to deal with forces that are not directly measurable. Boumans (1992) helpfully extends on this. In physics, a force ‘F’ is called elastic when it is proportional to the movement ‘x’ of the body on which it acts, so that F = *b*x. If a body hangs still on a spring, there is an equilibrium between the elastic force of the spring (pulling it upwards) and the gravitational force (pulling it downwards). Gravity itself is not measurable – but if we know the binding force of the spring, we can infer it from the setting.

Knowing the binding strength of a spring, in other words, helps us determine the gravitational force that works on a body, given information about the height at which the spring hangs. Similarly, knowing the organizational form of an exchange helps us determine the preferences of individuals in an Edgeworth-Bowley box, given information about the resulting distribution. Consequently, just like changing the (binding strengths of the) spring will alter the height at which the body hangs if the gravitational force stays the same, so will a change in the form of organization alter the distribution in an Edgeworth-Bowley box if the preferences of the individuals remain unchanged.

An important consequence was that Tinbergen again avoided direct interpersonal comparisons of utility itself, though with a slightly different strategy than in the 1925 notes. When one tries to achieve the optimal allocation of resources in the system described in the 1925 notes, we sidestep the need to compare utilities by asking which individuals want to exchange places with which other individual. This means that exchange does not take place by exchanging x for y one at a time, but by immediately switching one’s entire lot with that of another. The proxy for changes in utility is whether or not someone is willing to swap places. If an individual A wants to switch places with individual B, surely the share of different goods owned by B is deemed superior; if B wants to switch places as well, that switch must constitute a Pareto improvement. When we look for the optimal allocation of goods in the 1928 article, we ask for which distributions of x and y two individuals will not want to exchange more of x and y. If, given any distribution of x and y, individual A would like to exchange x for y, then surely that extra unit of y must have a higher utility than the unit x he is willing to forego; if at the same time individual B would like to exchange one unit of y for one unit of x, the exchange will occur and overall utility will be higher than before. In both cases, the interpersonal comparability of utility is avoided by using a proxy, just like the binding strength of a spring can be used as a proxy for determining the gravitational force.

Tinbergen’s use of binding equations is particularly interesting because Tinbergen’s ideas about organizing trade would become an important cornerstone of the work on economic planning that he would commence in the thirties. That Tinbergen had already formulated thoughts about influencing the result of market exchange without replacing the market mechanism was already discussed in section 3.2.2.

5.1.2. Friction and Cournot

A second instance of Tinbergen's use of physical terms can be found in his recurring discussion of Cournot duopolies. Cournot duopolies are a reaction to an important theoretical concept in microeconomics: the perfectly competitive market. A perfectly competitive is a kind of market with many producers and many consumers. This sets it apart from for example monopolies only one producer, oligopolies, in which there are only few producers, and monopsonies, in which there is only one consumer. Because a perfectly competitive market has many producers, each individual producer becomes a so-called 'price-taker': they have to sell their product at the market price. Any producer that charges a price higher than this equilibrium price will lose all his customers; any producer that charges a price below the equilibrium price will attract all demand. Because of this last incentive, an individual supplier has good reasons to slightly lower his price in order to attract more demand, because the decrease in revenue per product can be offset by the amount of products sold. As a result, the price will move down until it is equal to the marginal costs (cost per final product produced).

Cournot believed that that this was a poor representation of reality. One important reason for the difference is that producers in perfectly competitive markets are assumed to respond immediately to the price change of a competitor, whereas in reality it takes time for competitors to respond to each other. Cournot builds on this intuition by imagining a so-called 'duopoly', a market served by only two suppliers. In case one of the suppliers, the price-setter, lowers his price, it will take time for his opponent, the price-follower, to adjust his own price and production process. For the duration of this period, the price-setter will have higher revenues because the decrease in price is offset in revenue by an increase in the products sold. Afterwards, assuming that there are no significant differences between the production processes of the two suppliers, the market will normalize to the old situation – only with lower revenues for both.

Tinbergen first discussed Cournot duopolies in 1925, when he used them to illustrate the applicability of mathematics in economics. Cournot had represented his intuitions about duopolies in mathematical equations, which could usefully find the equilibrium prices and profits that would result from a price-change in a market. Since Tinbergen was at this point more concerned with proving *that* mathematics could be useful to economics, rather than *how*, he did not provide a conceptual explanation.

Cournot was discussed with more depth in a 1928 (June) article that Tinbergen wrote for the Socialistische Gids. This article was the second part of an article on theories of exchange, of which the first was discussed in the previous subsection. On Tinbergen's interpretation, Cournot's main innovation was his insight that equilibrium does not set immediately, as was assumed by conventional economic theories. These theories presupposed a view of a 'static society' that Tinbergen rejected:

> "Real economic phenomena do not show the peace of equilibrium, but a continuous movement around equilibrium, which by the way also continuously change themselves. The study of economic motion is indispensable for our understanding of these matters" (1928, p. 543, my translation)

The static view of economic motion should be understood as analogous to the movement of a pendulum in a frictionless space. This allows us to see that, contrary to the static view

> "In reality this "frictionless" motion of goods is impossible, turning the question at hand into a very simple instance of dynamic problems. One sees clearly that solving it requires further information, as it does in mechanical dynamics, to which we can refer with 'slowness' and 'deceleration', where the slowness refers to the difficulty, the deceleration on the time of movement. In reality, the two will correlate." (1928, p. 544, my translation).

Tinbergen continued to pursue the application of 'slowness' with some greater detail. He considered a market in which suppliers need one full month in order to adapt supply to price. This meant that the producers in the market will, at every point in time, offer the supply compatible with last month's price. His starting was formed by data on the supply and demand curve (Tinbergen, 1928):

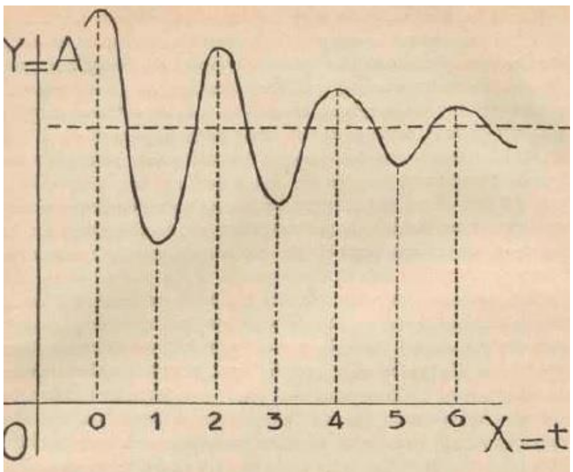
Price	0	1	2	3	4	**5**	6	7	8	9	10
Demand	16	12	10	9	8	**7**	5	4	3	2	1
Supply	0	2	4	5	6	**7**	8	9	10	11	11

In such a market, the equilibrium price would be 5. But if we instead assume Tinbergen' constraint that supply takes into account last month's price, and combine that with the assumption that last month's price was 8, the market price will oscillate until it converges in an equilibrium:

Time	-1	0	1	2	3	4	5	6	7	8
Price	8	2	7	3	6	4	5½	4½	5½	
Amount exchanged		10	4	9	5	8	6	7½	6½	

Tinbergen supplemented this example with *Dampened Production Cycle* Figure , which shows how the amount exchanged approaches an equilibrium value over time.

Tinbergen emphasized the generality of this kind of result; it gave credibility to the possibility that cyclical movements, in general, could be propagated by the system itself. Business cycles were mentioned as an example. The number of cycles that a system goes through – here interpreted as movements around the axis – could differ from one system to another. Tinbergen likened this to different levels of "dampening", a term which he again drew from physical motion. The level of dampening, or friction,



Dampened Production Cycle

Figure 7

influences whether a system sets in equilibrium slowly, quickly, or even explodes[18].

This article shows that his background in physics influenced Tinbergen's thoughts on cycles. Tinbergen uses the relation between mechanical concepts like "friction" and "motion" to explain how an economic system reacts to a shock. At the same time, it marks a development in Tinbergen's thought. In later years, Tinbergen would believe that cycles are caused endogenously: the cause of every cycle is contained within the previous cycle. This is contrary to the view, which would be defended by Frisch (1933), that cycles are exogenously caused, but endogenously propagated – the so-called 'Rocking Horse Model'. This model suggests that cycles are generated when an external shock, caused by an external force, is transformed into a cyclical motion by the economic system. On this reading, a cycle is not caused by the previous cycle, but by an external force. Tinbergen's 1928 approach to cycles is remarkable because he defends a view close to the Rocking Horse model, which he would later reject as an inadequate representation of business cycles.

5.1.3. A Dissertation on Physics and Economics: A Problem without Integrals

The work in which Tinbergen explored the use of physics for economics most extensively was the dissertation he wrote under Ehrenfest's supervision: 'Minimumproblemen in de Natuurkunde en de Ekonomie'. The largest part of Tinbergen's dissertation attempted to classify the different ways in which these minimum problems appear in physics, and to devise a way to represent them in one and the same form of differential equations. The economic addendum, which will be discussed here, relates the techniques with which physicists usually tackle minimum problems to economic affairs[19].

That Tinbergen treats economic problems in an addendum should not be taken to suggest that this was not an important part of the project, as becomes clear from the first sentence of the introduction:

> "The subject of this dissertation was chosen with special consideration for the analogies that would likely hold between these physical problems and particular economic problems, to which the appendix refers" (Tinbergen 1929 p. 1, my translation)

Tinbergen's treatment of economic problems attempted to show that instruments pertaining to minimum problems in physics may be useful to some economic problems as well. That Tinbergen was still cautious, as he had been in 'Wiskunde- Grenswaarde – Marx', is evident from the care with which he pointed out that he made no claim to exhaustiveness:

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[18] Tinbergen does not mention the possibility of stable cycles at this point.

[19] While the problems Tinbergen was concerned with are strictly speaking *maximization* problems rather than *minimization* problems – for example, under which conditions will profit be *maximized* – I will follow the title of his dissertation by calling them minimum problems.

> “In the following pages, we will attempt to sketch how theoretical economics, too, contains problems of the structure of the physical problems we have discussed, and how as a result economics can make use of the conclusions that have been found for these physical problems. Our discussion will in no way claim to be systematic or exhaustive in the economic sense of the word. One should merely see them as illustrations of the larger claim [that introducing mathematics of this kind into economics would be fruitful]” (p. 47-48, my translation)

Among problems that can be covered with differential equations, Tinbergen distinguished two kinds: those that do not involve integrals and those that do. Both in their own way relate problems of physics to problems of economics, and they will be considered in turn.

Tinbergen’s first[20] example contained three parts, which revolve around the example of a company. This company makes a particular final product by combining two production factors, denoted 1 and 2. The amount of product produced, denoted by ϕ, is a function of the amount of production factors 1 and 2 that is used, denoted by ξ_1 and ξ_2. The production function of this product is consequently given by $\phi(\xi_1, \xi_2)$. In addition, the prices of both production factors and the final product are fixed and respectively given by y_1, y_2 and y_0.

The first question Tinbergen asked is which combination of ξ_1 and ξ_2 would maximize return on investment[21]. The first step is the construction of a total revenue function and a total cost function. The total revenue function is derived by multiplying the production function with the given price for which the final product is sold. Tinbergen denoted this with Ψ, which can be understood as revenue as a function of ξ_1 and ξ_2.

(1) $$Total\ revenue\ function = y_0\phi(\xi_1, \xi_2) = \Psi(\xi_1, \xi_2)$$

The total cost function is derived by multiplying the quantities of production factors 1 and 2, i.e. ξ_1 and ξ_2, with the respective prices for which they are bought, i.e. y_1 and y_2.

(2) $$Total\ cost\ function = y_1\xi_1 + y_2\xi_2$$

Since total return on investment is total revenue minus the total costs, the total return on investment function is the following:

(3) $$Total\ return\ on\ investment\ function = \rho = \Psi(\xi_1, \xi_2) - y_1\xi_1 - y_2\xi_2$$

[20] The second example considers constrained optimization, but will not be treated here.

[21] Tinbergen reserves the use of the term ‘profit’ for the second part of the example.

At this point the question is for which values of ξ_1 and ξ_2 total return on investment ρ would be maximized. This leads us to ask under which conditions ρ is stationary[22] under very small changes in ξ_1 and ξ_2. To find out, we require partial derivatives for ρ with respect to ξ_1 and ξ_2.

(4) $$\frac{\partial \rho}{\partial \xi_1} = \frac{\partial \Psi}{\partial \xi_1} - y_1 \qquad \frac{\partial \rho}{\partial \xi_2} = \frac{\partial \Psi}{\partial \xi_2} - y_2$$

To find the point at which ρ is maximum, ρ should not change with a very small change in ξ_1, nor with a very small change in ξ_2. In other words, $(\partial\rho/\partial\xi_1)$ and $(\partial\rho/\partial\xi_2)$ should both equal 0. This implies that total return on investment is maximal when the following conditions are jointly satisfied:

(5) $$\frac{\partial \Psi}{\partial \xi_1} = y_1 \qquad \frac{\partial \Psi}{\partial \xi_2} = y_2$$

For the second question, Tinbergen introduced a second company which creates a different final product from the first company. The different companies will be denoted Company A and Company B. Tinbergen also introduced the notion of capital, denoted by 'm'. It is assumed that capital is fully invested in Company A and Company B in the respective amounts m' and m". The respective returns of investing in Company A and Company B are ρ' and ρ". Tinbergen then asked: under which conditions can these two companies, which make use of the same production factors, coexist?

To arrive at an answer, Tinbergen first constructed a total profit function for this society as a whole. Total profit, denoted by 'w', depends on the amount invested in Companies A and B and the returns on investment of each company. This signifies that the larger the share of capital that we invest in Company A, the more total profit will depend on the return on investment of Company A, and vice versa.

(6) $$w = m'\rho' + m''\rho''$$

The two companies can coexist, according to Tinbergen, when total profit w would not change as a result of a change in m' and m". To see this, imagine what the reason behind such a change could be: If moving one unit of capital from Company A to Company B would lead to a *decrease* of w, no investor would consider that move. After all, the return on investment must be higher for Company A, so the money is best spent on Company A ($\rho' > \rho''$). Conversely, if moving one unit of capital from Company A to Company B would lead to an *increase* of w, then the return on investment must be greater in Company B than in Company A ($\rho' < \rho''$). Investors would keep moving capital from Company A to Company B, until the point at which moving capital from Company A to Company B is no longer more profitable than keeping it in Company A. Consequently, capital will stop moving from one company to another when the returns on investment are equal ($\rho' = \rho''$).

Under the assumption that ρ' and ρ" are only dependent on the values of y_1 and y_2, there is a coexistence function $f(y_1,y_2)$ which renders all the values of y_1 and y_2 for which ρ' and ρ" are equal – and consequently, for which the two companies can coexist[23].

[22] Like Tinbergen, I will assume that this stationary point constitutes a maximum (and not a minimum or an inflection point).

The final part of the example asked what the relative shares of m' and m" would be in equilibrium. Tinbergen argued that this question has no definite answer, because the values of m' and m" are independent of ρ' and ρ". Additional constraints on the problem could create a definite answer. Tinbergen suggested that this would be the case if we require that a particular amount of products should be produced or that a particular amount of ξ_1 and ξ_2 should be used.

At this point, Tinbergen took a step back towards physics, and more particularly thermodynamics. The relations stated above, Tinbergen held, are in equally applicable to thermodynamic equivalents when their designations are changed.

Parallel to the first part of Tinbergen's example, the 'revenue function' $\Psi(\xi_1, \xi_2)$ can describe the internal energy of a substance as a function of the entropy of a mass-unit of the substance (ξ_1) and its volume (ξ_2). The variables y_1 and y_2, which used to stand for the prices for the respective production factors, then stand for negative temperature and pressure. Variable ρ stands for thermodynamic potential. Finding the values of ξ_1 and ξ_2 that maximize ρ would then show how temperature and pressure depend on volume and entropy in an equilibrium state.

The parallel with the second part of Tinbergen's example was created by imagining that the substance is present in both gaseous and liquid form. The mass of the substance that is present in liquid form is designated m'; the mass of the substance that is present in gaseous form is designated m". The 'coexistence question' no longer asks whether two *companies* can coexist, but whether *two phases of a substance* can coexist. Coexistence between the two phases is only possible when there is a particular relation between pressure and temperature that is known as the vapor pressure equation of that substance.

Tinbergen stated that "all general conclusions from the physical equations apply to the economic case that has been considered" (p. 50). An example is that we can calculate the change in ξ_2 that results from a change in y_1 if we know the change in ξ_1 as result from a change in y_2:

(7) $$\frac{\partial \xi_1}{\partial y_2} = \frac{\partial \xi_2}{\partial y_1}$$

For physical problems, this implies that we can deduce the influence of a change in pressure on the entropy of a mass-unit of a substance if we know how much volume changes in response to a change in temperature. For economic problems, this captures so-called substitution effects: If we assume that Company A produces cars with steel and labor as production factors 1 and 2 (ξ_1 and ξ_2), a rise in the price of steel (y_1) might make it desirable to buy less steel (ξ_1) but instead employ more labor (ξ_2), for example to recycle otherwise wasted steel.

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[23] Tinbergen does not acknowledge the special case in which ρ' = ρ" for negative values of ρ' and ρ", in which case both companies would not exist.

5.1.4. A Dissertation on Physics and Economics: A Problem with Integrals

The last part of Tinbergen's appendix explored how economic problems can be approached as minimum problems in which the value of an integral is maximized. Tinbergen stipulated four conditions that must be satisfied in order for an economic problem to be treated as a minimum problem:

> "an economic problem can seemingly be brought into the form of an optimization problem when the following conditions hold
>
> 1. There must be, as we have presupposed so far, only one ophelimity function;
> 2. It should be possible to approximate this [ophelimity function] with some integral;
> 3. The derivative of the quantity that is expressed as a function of the independent variable should appear in the integrand;
> 4. The quantity that is expressed should possess given values at its limits (or instead it should conform to its natural boundary conditions)." (p. 52, my translation)[24].

The first condition implies that the problem consists of a single function. This is not so much a requirement as a limitation of scope that Tinbergen acknowledged earlier in the appendix (p. 48). Tinbergen confined himself to problems with a single function because more complicated economic problems can be solved by breaking them down into problems of single functions. The second condition is exemplified by economic problems where the quantity in which we are interested is the sum of quantities over time. Tinbergen offers the example of total profit over a particular time period (say a year), which is the sum of profits contained within that time period (say the months). The third condition is fulfilled, for example, when a problem contains both a stock and a flow variable. In economics, a stock variable represents a quantity measured at one point in time, while a flow variable measures the change in a stock variable over a period of time. If we consider the amount of supplies owned by a company, the total amount owned would be a stock variable while the monthly (or weekly, or daily) change in supplies would be a flow variable. In the terms of condition 2, the total supply would be the integrand, while the change in supply would be the derivative. The fourth condition states the interval over which the integral should be calculated.

For an example from economics, let us consider Tinbergen's own treatment of supply problems. Imagine a company which sells an amount ξ of a product against a particular price p. This price is a function of the amount sold, to reflect that products become less expensive as more are available on the market, and time, so that $p(\xi, t)$. This company also has a particular supply stock, x, and the change in this stock is denoted by $\dot{x}$. Given these terms, it is possible to build functions for the revenues and the costs at each time t. With these functions, we can construct the function of profit at each time t. It is important to distinguish these revenues, costs and profits at time t from the revenues, costs and profits over the entire interval, which are described by an integral. Tinbergen asked for which values of x and ξ total profit will be maximal.

[24]For Tinbergen's use of 'ophelimity' as contrary to 'utility', see footnote 17.

For a time t, the revenue function is given by ξ p(ξ, t), or the amount of products sold times the price. The cost function contains two parts: one for the cost of production and one for the cost of holding stock. Holding stock comes at a cost K that depends on the amount of supply held and time, so that K(x, t) for a time t. Since all goods that are produced are either sold (as ξ) or added to supply (as a change in x), production equals $\xi + \dot{x}$. The production cost function at a time t, as a function of production and time, equals $k(\xi + \dot{x},t)$. Tinbergen writes $\xi + \dot{x}$ as y for convenience.

Total profit 'w' over the entire interval is given by the integral over the profit in each time period. It is therefore:

(9) $$w = \int_0^T dt\{\xi\, p(\xi,t) - K(x,t) - k(y,t)\}$$

To find the values of ξ and x for which w is maximal, we (as before) require partial derivatives towards ξ and x which, when both set to 0, render the stationary points of w. For x, using the product rule,

(10) $$-\frac{\partial K}{\partial x} + \frac{d}{dt}\frac{\partial k}{\partial y} = 0$$

One may have expected the second term, $\frac{d}{dt}\frac{\partial k}{\partial y}$, to be negative because the third term in w, k(y,t), is negative. While Tinbergen did not offer an explicit explanation why $\frac{d}{dt}\frac{\partial k}{\partial y}$ is positive, it may be because he implicitly assumed diminishing marginal returns in the production function. Diminishing marginal returns are a formal trait that is commonly postulated for production functions, and states that for a production function f, f' > 0 & f''<0. In a production function with multiple input factors, it signifies that returns to individual input factors will diminish if the other production factors remain constant. In this case, f''<0 would imply that $\frac{d}{dt}\frac{\partial k}{\partial y}$ is negative.

Then, for ξ:

(11) $$\xi\,\frac{\partial p}{\partial \xi} + p(\xi,t) - \frac{\partial k}{\partial y} = 0$$

Tinbergen then considered three special cases in order to show that presenting supply problems in this way can be insightful. The first special case is a situation in which K(x ,t) is 0, or where keeping a supply is costless. In that case (10) turns into (12):

(12) $$\frac{d}{dt}\frac{\partial k}{\partial y} = 0$$

Equation (12) implies that the slope of k with respect to y does not change, and is therefore a constant 'c' in time. Therefore (12) implies (13):

(13) $$\frac{\partial k}{\partial y} = c$$

Tinbergen continued towards the optimal values of ξ through a slightly different route than before. Instead of stating that profit is maximal for the values of ξ for which both this and the previous equation are zero, Tinbergen plugged this new equation into the partial derivative of profits over the entire interval with respect to products sold (11) to derive marginal profit per product.

(14) $$\xi \frac{\partial p}{\partial \xi} + p(\xi, t) - c = 0$$

Total profit will be maximized when marginal costs (c) and marginal benefit ($\xi \frac{\partial p}{\partial \xi} + p(\xi, t)$) – or, alternatively, one can look at this as trying to find the values for marginal profit equals 0, i.e. the point after which producing and selling an additional product would make the function of profit over the entire interval decline.

The second special case is when keeping supplies is impossible, i.e. where x = ẋ = 0. With supply no longer in play, marginal profit is a function of t and ξ. We then try to find the value of ξ for which marginal profit is 0.

(15) $$\xi \frac{\partial p}{\partial \xi} + p(\xi, t) - \frac{\partial k}{\partial \xi} = 0$$

The third special case homes in on the role of time. That the price (a function of ξ and t) and cost of production (a function of ξ + ẋ and t) are functions of time can be used to reflect periodic cycles. In the case of the price, that can be used to incorporate changing demands: the demand for coal, for example, will be higher in winter than in summer. That costs are a function of time may reflect that the costs of particular factors may vary over time: for example, the cost of timber will be higher in winter than in winter.

Finally, Tinbergen asked whether this problem can also generate a periodic cycle if all variables of independent of time. To prove that this is possible, Tinbergen presented a form of the above functions for which that would be case. Assume the following specifications of K, k and P as functions of x, y and ξ:

(16) $$K\ (x) = A + Bx + \tfrac{1}{2}Cx^2$$

(17) $$k(y) = a + by + \tfrac{1}{2}cy^2$$

(18) $$p = P - Q\xi$$

Under this specification, w will be maximal for values of x that follow from x = x_0 + z if

(19) $$z = \frac{2cQ}{(2Q+c)C} z" \; where \; \frac{2cQ}{(2Q+c)C} < 0$$

The term $\frac{2cQ}{(2Q+c)C}$ must be negative, because z would be a straight line if it were 0 and would explode if it were positive.

This example shows how, according to Tinbergen, this mathematical treatment of economic problems could be helpful. Firstly, this treatment of economic problems allows quantity, change in quantity and the change of that change to depend on each other – a dependency which, as the supply problem illustrates, is often present in economic problems. Secondly, this treatment allowed Tinbergen to emphasize a number of interesting aspects of the problem that mathematical treatment brings to the foreground. That this supply problem can even render periodic results if all variables are time-invariant is a result that would have been more difficult to arrive at through conventional economic theorizing.

Dynamic

After his exposition on supply problems, Tinbergen applied a similar treatment to friction problems (profit as a function of the production per time unit and the cost of changing the production per time unit) and retardation problems (where fixed lags are approximated by a differential equation). This last category deserves special emphasis, considering the development of Tinbergen's use of the word 'dynamic' during this early period and his later work.

Tinbergen already used the work 'dynamic' in the context of economic problems in his 1927 article 'Over de Mathematies-Statistiese Methoden voor Konjunktuuronderzoek'. In that article Tinbergen considered how different economic variables may 'lag' behind each other, that is, correlate with a certain time difference between them. That way of representing business cycles had become typical of business cycle research as it was pioneered in the United States (Boumans 1992). Tinbergen commented that such 'lags' could be the building blocks of an "economic dynamics" (p. 715) from which 'purely' periodic fluctuations can be deduced. In his dissertation, Tinbergen applies the term 'dynamic' to those problems in which can be approximated with an integral (p. 52). The 'dynamic' nature of a problem is, in other words, a prerequisite for treatment as a minimum problem. Tinbergen acknowledged the relevance of difference equations, i.e. equations with lags in them, but only to point out that they can (under the right conditions) be approximated with differential equations. While the 1927 article suggested that difference equations can classify as 'dynamic' in their own right, the 1929 dissertation suggests that they only qualify if they are approachable by a differential equation.

The first development, then, is from a notion of dynamic that emphasized difference equations to a notion of dynamic that accepted difference equations, but centered on differential equations. The second development was a step back: In all of Tinbergen's later works, dynamic problems are those that contain difference equations. One example is his 1935 work '*Annual Survey: Suggestions on Quantitative Business Cycle Theory'* (1935), in which Tinbergen would refer exclusively to difference equations when he states that a theory is dynamic "when variables relating to different moments appear in one equation" (p. 241).

5.2. Innovation and Continuity in Tinbergen's use of Physics

5.2.1. Transfer of Metaphor, Transfer of Method

The previous subsection has shown that Tinbergen's background in physics played an important role in his early economic writings. This subsection will provide Tinbergen's use of physics for economic purposes with historical context. It will argue that the pre-existing exchange between physics and economics – of which Ehrenfest was aware – has helped Tinbergen to exploit other similarities. In addition, Tinbergen's approach to such similarities is different from the dominant tradition, and marks a discontinuity between him and Paul Ehrenfest.

Paul Ehrenfest and Jan Tinbergen weren't the first to draw the link between physics and economics. Consider for example Philip Mirowski's claim that neoclassical economists in the 19th and early 20th century drew upon the conservation of energy as a metaphor for utility and that this lead to problems for neoclassical economics even today. In physics, the law of the conservation of energy dictates that energy is never lost, but only transformed from one form into the other. The convenience of the law of conservation of energy lay in its ability to represent physical systems as a closed, deterministic system in which a change in the value of a known variable – heat, for example – must automatically imply a change in another variable, given that the whole must be conserved. Mirowski argues that economists appreciated the formal, deterministic virtues of these physical innovations and tried to mimic them in economics by 'transferring the metaphor' of the conservation of energy. He describes the attempts of amongst others Walras, Jevons and Fisher to translate physical concepts into economic equivalents. Fisher even provided readers with a table in which he explained which economic concepts had what physical counterparts (Fisher 1925, p. 85):

"In Mechanics		In Economics.
A particle	Corresponds to	An individual.
Space	" "	Commodity.
Force	" "	Marg. ut. or disutility.
Work	" "	Disutility.
Energy	" "	Utility.

Work or Energy = force x space	Disut. Or Ut. = marg. ut. x commod.
Force is a vector (directed in space).	Marg. ut. is a vector (directed in com.)
Forces are added by vector addition.	Marg. ut. are added by vector addition.
("parallelogram of forces.")	("parallelogram of marg. ut.)
Work and Energy are scalars.	Disut. and ut. are scalars."

While Ehrenfest never published on economics, his notes contain tables that, much like Fisher, relate concepts from physics to economics (Klein 1970; Hollestelle 2011). Ehrenfest even gave this enterprise its own name: in the spirit of the analogy with thermodynamics, he called it Ökodynamik – a contraction between 'Ökonomie' and 'Thermodynamik'.

In reaction to Mirowski's thesis that exploitation of similarities between physics and economics involves 'transfer of metaphor', at least for the cases he is concerned with, Marcel Boumans suggested that Tinbergen's use of physics might be of a different sort. Boumans' central claim is that Tinbergen transferred the methodology, rather than the metaphors, of physics. Largely on the basis of Klein's biography of Ehrenfest, Boumans argues that the underlying mechanism was a notion of 'physical analogy' that ultimately derives from Maxwell, and arrived at Ehrenfest through Boltzmann. To consider why Boumans believes Tinbergen to be different, it is helpful to first say some more about physical analogies.

According to Klein, the philosophy behind physical analogies traces back to James Clerk Maxwell. In his earliest work on electromagnetism, Maxwell chose not to start from a mathematical model or a particular physical hypothesis. Instead, he introduced the notion of 'physical analogies': "that partial similarity between the laws of one science and those of another which makes each of them illustrate the other" (p. 155). The idea behind physical analogies was that if two systems could partly be represented in the same mathematical form, then we could derive useful knowledge about the lesser known system from our knowledge of the better known one. Since these lessons depended only on mathematical similarity, one could avoid dependence on physical hypotheses.

This idea, that one could draw lessons for one system by looking at purely formal analogies with another, arrived at Heinrich Hertz through Hermann von Helmholtz. Hertz took it a step further: instead of looking at the physical analogy between two physical systems, he looked at the analogy between a mathematical system and a physical system. In particular, he constructed a theory that represented movement as the consequence of 'concealed masses' rather than as the result of the exertion of force. Within this theory, physical systems were represented as a three-dimensional grid filled with both observable and concealed masses. By attributing behavior that was not due to the presence of observable masses to these new concealed masses, Hertz created a system in which any notion of 'force' was obsolete. His own philosophical corollary was that the presence of concealed masses made purely empirical physical theories necessarily incomplete. These theories are, after all, only able to take into account observable masses, and will therefore be disturbed by the behavior caused by concealed masse. This is why he believed that the apex of mechanical explanation was an analogy of the kind described by Maxwell: "in order to determine beforehand the course of the natural motion of the material system, it is sufficient to have a model of that system" (Hertz, 1956 (1894), p. 175-177).

Hertz' formulation of physical analogies was gratefully accepted by Boltzmann. Boltzmann is mainly known for developing statistical mechanics. Classical mechanics had presupposed that systems of particles could only be described by first describing the behavior of the individual particles, and then drawing conclusions for the system. Statistical mechanics, on the other hand, took the behavior of the system as its starting point. This change of emphasis presupposed a different epistemological commitment: while it was the aim of classical mechanics to describe the world 'as it really is', statistical mechanics holds that physical theories should provide as much insight as possible by providing phenomena with a clear and simple representation (Boumans, 1993). As a corollary, physical theories about the same phenomena were no longer necessarily mutually exclusive. Different theories could be maintained because of the different insights they provided.

Boltzmann welcomed the philosophical notion of the physical analogy because it allowed him to make claims about the behavior of groups of particles without making ontological claims about the nature of individual particles. With regards to Hertzian mechanics, Boltzmann was not so unequivocally positive. His doubts did not prevent him, however, from suggesting it as a suitable topic for the dissertation of Paul Ehrenfest. While this dissertation is itself not relevant to this thesis, the fact that Ehrenfest worked on Hertzian mechanics under the close supervision of Boltzmann makes a case for Ehrenfest's familiarity with physical analogies in the tradition of Maxwell.

Boumans then makes the step from Ehrenfest to Tinbergen, largely because Tinbergen was indeed greatly influenced by his mentor:

> "In Tinbergen's dissertation, the analogy was provided by Lagrange's dynamical equations. The applied method was Maxwell's method. To the extent that economic systems can be described by the same mathematical formalism as physical systems, understanding of the behavior of economic systems can be obtained by studying the behavior of better known systems in physics." (p. 118)

While I agree with Boumans larger point, namely that Tinbergen used the physical method but not its 'metaphor', in Mirowski's sense of the word, I am not entirely convinced by this point about physical analogies.

The problem with attributing Tinbergen's approach to Maxwell's physical analogies is that the method of using these analogies seems to have changed along the lineage that Klein has sketched. For Maxwell, a 'physical analogy' required that the laws of two systems are similar enough. The analogy is then between two independent physical systems, both represented by at least partial formalisms. If system A is familiar and system B is not, and the formalism of system B is at least partially similar to the formalism of system A, then we may helpfully deduce tentative insights about B from A – tentative, because Maxwell was careful to state that an analogy was not a substitute for "a mature theory, in which physical facts will be physically explained" (Maxwell 1855 as cited by Klein, p. 56). For Hertz, the analogy was not between two physical systems but between a model and a system. The model should describe the system in the simplest of terms; empirical data should not be taken as leading, because of the existence of 'concealed masses'. In addition, he believed that Maxwell's analogies were the only way in which mechanical explanations could be understood. This means that, contrary to Maxwell, he sees no need (nor possibility) for a 'mature physical theory' to replace analogies. Boltzmann's use of analogies is arguably closer to Hertz than to Maxwell: Boltzmann does not compare two systems, but a system of particles and a statistical model about them.

Fitting Tinbergen in Maxwell's tradition seems equally difficult. Maxwellian analogies would require that economics was at least partially formalized. These early works by Tinbergen did not start from economic formalisms, let alone formalisms that were comparable to those found in physics. In fact, when Boumans points out that “Tinbergen was deeply impressed by Ehrenfest’s didactic capabilities, and it became Tinbergen’s own scientific style to work out the simplest form in which some concept makes its entrance into a series of generalizations of some highly simplified initial scheme” (Boumans 1992, p. 117), it would seem that Tinbergen was closer to Hertz’ use of analogies.

5.2.2. Discontinuity between Ehrenfest and Tinbergen

While Boumans’ is right to point out significant continuity between Ehrenfest and Tinbergen, there is also an important point of discontinuity that he does not address. One regards the mode of the analogy; the other regards its direction.

With regards to the mode of the analogy, the methods of Ehrenfest and Fisher differ from the method of Tinbergen in that the former builds on an analogy between *concepts*, while the later builds on an analogy between *relations*[25].

To see why the method of Ehrenfest and Fisher builds on an analogy of concepts, recall that the method of Ehrenfest and Fisher juxtaposes physical concepts with economic concepts. For Fisher a particle was analogous to an individual; utility was analogous to energy, and so on. This analogy could be called an analogy of concepts. While they do derive relations from that analogy, these relations are secondary; they follow logically once the analogy of concepts has been accepted. The analogy of concepts is, in other words, prior.

Tinbergen turned this upside down. This is best illustrated with a number of examples. First, there was the example of friction in Tinbergen’s treatment of production cycles. When Tinbergen invoked friction to illustrate dampening, he did not start by postulating an analogy between physical and economic concepts, e.g. between pendulums and producers or economies, or between velocity (of the pendulum) and the adjustment rate of production. His analogy homed in, instead, on the relation *between* concepts: in this case, the relation of the velocity and its rate of change, on the one hand, and production and its rate of adjustment, on the other.

The same is the case in Tinbergen’s dissertation. Consider the first example from the dissertation that was explained in the above, where Tinbergen constructed an example on the basis of two companies, their production factors and capital and later likens it to a substance’s vapor pressure equation in physics. In that example, it is the relations between variables that Tinbergen considered similar in both instances: the relation between pressure, entropy, volume and temperature is analogous to the relation between the prices and quantities used of two production factors. Tinbergen stated this without presupposing or arguing that the concepts are analogous themselves; the step to deriving an analogy of concepts is not even made.

Another instance of analogies of relations is the second part of Tinbergen’s dissertation. When Tinbergen set forth under which conditions economic problems can be treated like minimum problems in

[25] I’m grateful to Marcel Boumans for his help with developing my thoughts on this.

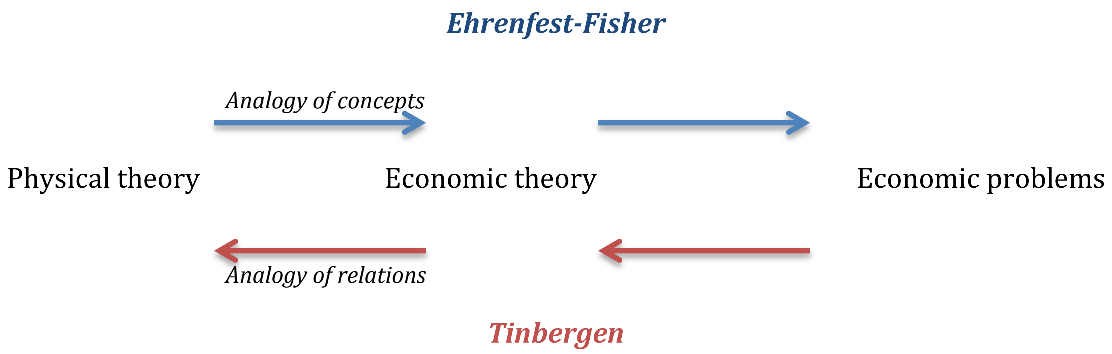
physics, he specifies that they should contain an integral, an integrand and a derivative. This specification takes the form of a relation – the concepts themselves are, at this stage, not relevant.

To clarify the difference between the two accounts, it should be helpful to stipulate that the account of Fisher & Ehrenfest did not *exclude* the use of analogies of relations, just like Tinbergen's account did not *exclude* the use of analogies of concepts. The difference between the two accounts was that they take a different analogy to be primary.

The second difference between the methods of Ehrenfest & Fisher and that of Tinbergen was one of direction – the two methods have different starting points.

In the Ehrenfest-Fisher approach, the starting point of the exchange was constituted by a physical theory. An economic theory was formed by assuming an analogy between the economic theory and the physical theory – an analogy of concepts, I have just argued, but that is not relevant here. This economic theory can then be used to analyze economic problems.

Tinbergen started on the other side: economic problems are his main inspiration. As we have seen, Tinbergen first formulated these problems in the terms of familiar economic theories. It is only at that point that he turned to physics. This means that Tinbergen already had a mature economic framework *before* turning to physics, which was not the case for Ehrenfest and Fisher's use of analogies.



Two different approaches towards the use of physics for economics

Figure 8

When it comes to the way that Ehrenfest and Tinbergen used physics for their economic work, there are two concrete differences: the two approaches made use of a different kind of analogies and had different starting points (see *Two different approaches towards the use of physics for economics* Figure). These insights complement the views of Boumans, who points to important continuities between the work of Ehrenfest and Tinbergen. Boumans does not stand alone in pointing to Maxwell as the one who paved the road for the exploitation of similarities between disciplines. In this broad sense, Tinbergen's use of physical tools in economics was indeed part of Maxwell's legacy. This should, however, not lead us to ignore important differences that exist between their respective uses of similarity, in particular when there is good reason to conclude that the way in which Tinbergen made use of similarities actually constituted a break with that of his mentor, Paul Ehrenfest.

5.3. Conclusion

This chapter has aimed to show how Jan Tinbergen used his physical background to his advantage during his work in economics. Apart from expanding on the different instances in which Tinbergen put his physical background to work, this chapter has also shown that there is a pre-existing tradition of exchange between physics and economics. Tinbergen renewed this tradition through his novel approach towards similarities, which built on analogies between relations rather than between concepts. In addition, Tinbergen's method took economic problems as its starting point instead of physical theories, as conventionally had been done when similarities between the two disciplines were explored.

6. Jan Tinbergen, Economist

By the time this story ends, Tinbergen is slowly becoming a renowned economist. In 1931, Tinbergen would accept a position as 'privaatdocent' (a teaching function) at the University of Amsterdam. A report from 'Het Volk' shows that his promise as an economist was clear by then:

> "Even for novices it was clear, that someone was speaking who – on a broad mathematical basis – makes a thorough study of economic life. A similar combination is hard to come by in the current state of management sciences, but also rarely accomplished. It is in our fellow party-member Tinbergen that we find this valuable "hybrid" between mathematician and economist. Hopefully many students of the University of Amsterdam use this occasion to pursue a deeper insight in political economics and mathematics – and in particular in their combination." (Het Volk, 3rd of October 1931, my translation)

Only two years later, in 1933, Tinbergen was given a chair in statistical analysis at the Rotterdam School of Economics. It would be the start of a very fruitful academic career during which Tinbergen would make a lasting impact on the economic science.

This thesis has argued that Tinbergen's transition from physics to economics, which was then arguably completed, should be understood in the context of his political beliefs, the particular philosophical and societal developments that surrounded the university and the use to which physical methods could be put in economics. After all, considering these themes individually would paint an incomplete picture. Locating Tinbergen's motivations exclusively in his political beliefs may offer an explanation for why he left physics, but not for why it was economics that he gravitated to. To understand that, we need to know how he believed physics could benefit economics. At the same time, we cannot understand Tinbergen's transition separate from the broader societal context, because it would underestimate the extent to which his environment played a part.

In addition to answering why Tinbergen moved towards economics, this study has also shown how Tinbergen's background in physics influenced both his political and economic writings. In his political writings, his background helped form the technocratic view that many societal problems are best approach as engineering problems. Approaching problems in this way fostered a conciliatory tone, by acknowledging that seemingly opposing points of view could be represented as accepting the same system, but with different specifications of the parameters. In his economic writings, Tinbergen would draw analogies between particular relations in physics and particular relations in economics. Apart clarifying his understanding of economic problems, this approach was also innovated the existing tradition of exchange between the two disciplines by emphasizing an analogy between relations instead of an analogy between concepts.

Finally, this study of Tinbergen's early years can inform contemporary debates on the relation between economics and policy and the role of mathematics in economics. These debates have been briefly introduced in the introduction.

The first concern was that the use of technocratic tools in policy crowds out political decision making. While this study does not make any claim about whether that has *in fact* happened, it does show that using (social) science to inform policy does not *necessarily* replace political beliefs. Tinbergen represented societal problems as technical problems so he would be able to influence them more effectively. In his case, this influence should direct towards a more equal distribution of wealth and income, but Tinbergen explicitly allows for the possibility that others, by setting the parameters differently, could pursue different results.

The second concern was that the mathematization of economics may abstract economic problems to the extent that it no longer relates to them. While Tinbergen's case, again, does not reflect on this issue directly, it is informative in two ways. First, it shows a number of ways in which mathematization can serve economics: it can clarify economic problems, summarize data, combine relations more clearly than theory can, and show interdependencies that would be difficult to ascertain without it. Tinbergen lauded man y of these benefits in his first writings, from which the epigraph derived. At the same time, the case of Jan Tinbergen shows that even he, who clearly advocated the mathematization of economics, saw the limitations. Introducing mathematical methods from other sciences was only warranted if the economic problems to which they were applied were suitable. Mathematization is, in other words, not an improvement in any circumstance and at all costs.

Sources

Note on translations

This study makes use of a number of primary sources in Dutch. In the case of block quotes, the translator is always mentioned. In the case of shorter, in-text citations, translations are always my own unless otherwise specified. The names of the periodicals for which Tinbergen wrote were translated the first time they were mentioned, and mentioned in Dutch afterward. For an overview, consider the following:

Dutch	*English*
De Economist	The Economist
Kentering	Change
Het Volk	The People
De Socialistische Gids	The Socialist Guide
Mensch & Maatschappij	Person & Society
Encyclopaedisch Handboek van het Moderne Denken	Encyclopedic Handbook of Modern Thought

Letters

The following is a list of letters that have been used, in chronological order.

Ehrenfest Scientific Correspondence

Letter from Ehrenfest to Schumpeter, 3rd of May 1918, ESC10:146[26]

Letter from Tinbergen to Ehrenfest, 2nd of November 1928, ESC9:384

Letter from Tinbergen to Ehrenfest, 23rd of December 1928, ESC9:389

Letter from Ehrenfest to Tinbergen, 2nd of March 1929, ESC9:404

Letter from Tinbergen to Ehrenfest, 20th of March 1929, ESC9:405

Letter from Ehrenfest to Tinbergen, 20th of March 1929, ESC9:406

Letter from Tinbergen to Ehrenfest, 16th of February 1930, ESC10:2

Letter from Ehrenfest to Tinbergen, 21th of April 1930, ESC 10:5

Erasmus University Tinbergen Archives

Letter from Van Lohuijzen to Tinbergen, 5th of April 1927, 001L008

Letter from Verrijn-Stuart to Tinbergen, 22nd of July 1928, 001E007

[26] I cited this letter from Hollestelle (2011). He refers to this letter as a letter from Ehrenfest to Schumpeter, 3rd of May 1918, ESC10 section 5. While there are no letters to Schumpeter present in ESC10 section 5 according to Wheaton's catalogue of the Ehrenfest Archives (1977), ESC10:146 is the only entry in ESC 10 section 5 that conforms to this date.

Figures

Bibliography

Aftalion, A. (1927). The Theory of Economic Cycles Based on the Capitalistic Technique of Production. *Review of Economic Statistics*, 165-170.

Alberts, G. (1994). On Connecting Socialism and Mathematics: Dirk Struik, Jan Burgers, and Jan Tinbergen. *Historia Mathematica*, 280-305.

Alberts, G. (1998). *Jaren van Berekening.* Amsterdam: Amsterdam University Press.

Baneke, D. (2008). *Synthetisch denken: natuurwetenschappers over hun rol in een moderne maatschappij, 1900-1940.* Hilversum: David Baneke & Uitgeverij Verloren.

Boumans, M. (1989). De constructie van de samenleving. *Beleid & Maatschappij*, 230-245.

Boumans, M. (1992). *A Case of Limited Physics Transfer: Jan Tinbergen's Resources for Re-shaping Economics.* Amsterdam: Thesis Publishers.

Boumans, M. (1993). Paul Ehrenfest and Jan Tinbergen: A Case of Limited Physics Transfer. In N. de Marchi, *Non-Natural Social Science: Reflecting on the Enterprise of More Heat than Light* (pp. 131-156). Durham and London: Duke University PRess.

Christiaan Huygens Debating Society. (1923). *Minutes of the Christiaan Huygens Debating Society.* Leiden: Christiaan Huygens Archive.

Dirks, J. (1929). Vraagstukken van Socialistiese Ekonomie. *De Socialistische Gids*, 528-540.

Dullaart, M. (1984). *Regeling of vrijheid: Nederlands economisch denken tussen de wereldoorlogen.* Alblasserdam: Offsetdrukkerij Kanters B.V.

Ehrenfest, P., & Ehrenfest, T. (1911). Begriffliche Grundlagen der statistischen Auffassung in der Mechanik. In *Encyklopädie der mathematischen Wissenschaften mit Einschluss ihrer Anwendungen* (pp. Vol IV, Part 2, Article IV 32). Leipzich: Teubner.

Ehrenfest, T. (1946). *Relevia: Een nieuw economisch system, een orde, waarin ik zelf ook graag zou willen leven.* The Hague: Boucher.

Elsbach, A., De Graaf, H., Jordan, H., Proost, K., & Van Senden, G. (1931). *Encyclopaedisch Handboek van het Moderne Denken.* Arnhem: Van Loghum Slaterus.

Fisher, I. (1925). *Mathematical Investigations into the Theory of Value and Prices.* New Haven: Yale University Press.

Frisch, R. (1933). *Propagation problems and impulse problems in dynamic economics.* London and Woking: Unwin Brothers Ltd.

Frisch, R., Fisher, I., & Roos, C. F. (1930, November 29). *Announcement of the December 1930 organizational meeting in Cleveland.* Retrieved September 4, 2014, from www.econometricsociety.com: https://www.econometricsociety.org/sites/default/files/historical/OriginalAnnouncement29%2011%2030.pdf

Groeneveld, G. (1952). Enige aspecten van de ontwikkeling van het economisch inzicht tussen de beide wereldoorlogen. In P. Kreukniet, *De Nederlandse Volkshuishouding Tussen Twee Wereldoorlogen.* Utrecht/Antwerpen: Het Spectrum.

Hertz, H. (1956 (1894)). *The Principles of Mechanics Presetned in a New Form.* New York: Dover.

Het Volk. (1931, November 3). Tinbergen's eerste college: Samenwerking economie en wiskunde. *Het Volk*.

Hollestelle, M. (2011). *Paul Ehrenfest. Worsteling met de moderne wetenschap, 1912-1933.* Leiden: Leiden University Press.

Idenburg, P. J. (1952). Geschiedenis der Nederlandse Statistiek. In P. Kreukniet, *De Nederlandse Volkshuishouding Tussen Twee Wereldoorlogen.* Utrecht/Antwerpen: Het Spectrum.

Jolink, A. (2003). *Jan Tinberen: the Statistical Turn in Economics 1903-1955.* Rotterdam: Chimes.

Kalshoven, F. (1993). *Over marxistische economie in Nederland, 1883-1939.* Amsterdam: Thesis publishers.

Klaver, J. (2015). *De Mythe van het Economisme.* Amsterdam: De Bezige Bij.

Klein, M. J. (1970). *Paul Ehrenfest: The Making of a Theoretical Physicist.* Amsterdam: North-Holland.

Krugman, P. (2009, September 2nd). *www.nytimes.com*. Retrieved June 8th, 2014, from The New York Times: http://www.nytimes.com/2009/09/06/magazine/06Economic-t.html?pagewanted=all&_r=0

Maxwell, J. (1855). On Faraday's Lines of Force. In J. C. Maxwell, *Sci. Papers I.*

Mirowski, P. (1989). *More Heat than Light.* Cambrdige: Cambridge University Press.

Naarden, G. M. (1989). *Onze jeugd behoort de morgen... De geschiedenis van de AJC in oorlogstijd.* Amsterdam: Stichting beheer IISG.

Nussbaum, M. C. (2001). The Cost of Tragedy: Some Moral Limits of Cost-Benefit Analyssi. In M. D. Adler, & E. A. Posner, *Cost-benefit analysis: legal, economic, and philosophical perspectives* (pp. 169-200). Chicago: University of Chicago Press.

Planck, M. (1900). Zur Theories des Gesetzes der Energieverteilung im Normalspektrum. In M. Planck, *Verh. d. Deutsch. Phys. Ges.* (p. p. 237).

Polanyi, K. (1922). Neue Erwägungen zu unserer Theorie und Praxis. *Der Kampf*, 18-24.

Redactie Het Volk. (1931, October 3). Tinbergen's eerste college: samenwerking economie en wiskunde. *Het Volk*, p. p. 3.

Redactie Kentering. (1926, June). Pinksteren 1926. pp. 113-115.

Richardson, H. S. (2000). The Stupidity of the Cost-Benefit Standard. *The Journal of Legal Studies*, 971-1003.

Rodenburg, P. (2014). Ingenieurs van de samenleving: De opkomst van het technocratisch denken in de Verenigde Staten en Nederland. *Tijdschrift voor Geschiedenis*, 271-291.

Tarascio, V. J. (1969). Paretian Welfare Theory: Some Neglected Aspects. *Journal of Political Economy*, 1-20.

Tinbergen, J. (1924, May). Verstand of gevoel. *Kentering*, pp. 24-25.

Tinbergen, J. (1925, March 3). Een Mijlpaal op de Weg. *Het Volk*, p. 8.

Tinbergen, J. (1925, May/June). Produksie en Behoefte(bevrediging). *Kentering*, pp. 100-101.

Tinbergen, J. (1925, March). Wiskunde - Grenswaarde - Marx. *Kentering*, pp. 65-68.

Tinbergen, J. (1926, June). "Wat we moeten doen". *Kentering*, pp. 117-119.

Tinbergen, J. (1926, September 14). Letter to Wibaut. *Wibaut Archives, IISG, Amsterdam [Original in Dutch]*.

Tinbergen, J. (1926, February). Uit een Andere Wereld. *Kentering*, pp. 57-58.

Tinbergen, J. (1927, April). Meer daden. *Kentering*, pp. 82-84.

Tinbergen, J. (1927, December). Over de mathematies-statistische methoden voor konjunktuuronderzoek. *De Economist*, 711-723.

Tinbergen, J. (1927, July 15). Tewerkstelling-premie. *Het Volk*, p. 7.

Tinbergen, J. (1927, October). Wetenschappelijk sosialisties werk. *Kentering*, pp. 5-9.

Tinbergen, J. (1928, June 19). "Werk, productief werk!". *Het Volk*, p. 14.

Tinbergen, J. (1928). De Roulering in het Werklozenleger. *De Economist*, 772-782.

Tinbergen, J. (1928, February). Macht en Ekonomiese Wet. *Kentering*, pp. 57-60.

Tinbergen, J. (1928, May). Opmerkingen over Ruilteorie. *De Socialistische Gids*, 431-445.

Tinbergen, J. (1928, June). Opmerkingen over Ruilteorie (slot). *De Socialistische Gids*, 539-548.

Tinbergen, J. (1928, September 15). Werktijdverkorting een middel tegen werkloosheid? *Het Volk*, p. 14.

Tinbergen, J. (1929, October). Economisch Getij. *De Socialistische Gids*, 849-858.

Tinbergen, J. (1929, May). Het Konjunktuurvraagstuk. *Kentering*, pp. 103-104.

Tinbergen, J. (1929, June). Konjunktuurtheorieën en -bestrijdingen. *Kentering*, pp. 119-121.

Tinbergen, J. (1929). *Minimumproblemen in de natuurkunde en de ekonomie.* Amsterdam: H.J. Paris.

Tinbergen, J. (1930). Bestimmung und Deutung von Angebotskurven: Ein Beispiel. *Zeitschrift für Nationalökonomie*, 669-679.

Tinbergen, J. (1930, January 27). Het Bevolkingsvraagstuk. *Het Volk*, p. 18.

Tinbergen, J. (1930, July). Mathematiese Psychologie. *Mensch en Maatschappij*, 48-58.

Tinbergen, J. (1930, August 25). Vóór Marxistisch? *Het Volk*, p. 18.

Tinbergen, J. (1931, October 2). Bedrijf en statistiek: Toenemende beteekenis der wiskundige methode van analyse. *Het Volk*, p. 9.

Tinbergen, J. (1931, January 19). De Werkloosheid als Wereldverschijnsel. *Het Volk*, p. 3.

Tinbergen, J. (1931). Kapitaal & Kapitalisme. In A. Elsbach, H. De Graaf, H. Jordan, K. Proost, & G. Van Senden, *Encyclopaedisch Handboek van het Moderne Denken* (pp. 633-636). Arnhem: Van Loghum Slaterus.

Tinbergen, J. (1931). Organisatie, Maatschappelijke. In A. Elsbach, H. De Graaf, H. Jordan, K. Proost, & G. Van Senden, *Encyclopaedisch Handboek van het Moderne Denken* (pp. 159-163). Arnhem: Van Loghum Slaterus.

Tinbergen, J. (1931). Statistiek. In A. Elsbach, H. De Graaf, H. Jordan, K. Proost, & G. Van Senden, *Encyclopaedisch handboek van het moderne denken* (pp. 400-405). Van Loghum Slaterus.

Tinbergen, J. (1931). Waardeleer. In A. Elsbach, H. De Graaf, H. Jordan, K. Proost, & G. Van Senden, *Encyclopaedisch Handboek van het Moderne Denken* (pp. 547-552). Arnhem: Van Loghum Slaterus.

Tinbergen, J. (1931). Wiskundige Methoden in de Economie. In A. Elsbach, H. De Graaf, H. Jordan, K. Proost, & G. Van Senden, *Encyclopaedisch Handboek van het Moderne Denken* (pp. 586-589). Arnhem: Van Loghum Slaterus.

Tinbergen, J. (1935). Annual Survey: Suggestions on Quantitative Business Cycle Theory. *Econometrica*, 241-308.

Tinbergen, J. (1937). De mogelijkheid van economische calculatie in een volledig gesocialiseerde maatschappij. *De Socialistische Gids*.

Tinbergen, J. (1939). *Business Cycles in the United States of America, 1919-1932.* Geneva: League of Nations.

Tinbergen, J. (2013). Recollections of professional experiences. *PSL Quarterly Review*, 331-360.

Tinbergen, J., & Oudegeest, J. (1925, October). Sosialisatie I. pp. 3-6.

Tinbergen, J., & Oudegeest, J. (1926, January). Sosialisatie II: Concrete plannen. *Kentering*, pp. 38-41.

Van der Wijk, J. (1930, August 4). Hooge inkomens, socialisten en socialisme. *Het Volk*.

Van Lunteren, F. H., & Hollestelle, M. J. (2013). Paul Ehrenfest and the Dilemmas of Modernity. *Isis*, 504-536.

Verwey-Jonker, H. (1938). Vijfentwintig jaar socialistische theorie. In J. Albarda, *Een kwart eeuw parlementaire werkzaamheid in dienst van de bevrijding der Nederlandse arbeidersklasse.* Amsterdam: De Arbeiderspers.

Wheaton, B. (1977). *Catalogue of the Paul Ehrenfest Archive at the Museum Boerhaave Leiden.* Leiden: Museum Boerhaave.

Wilts, A. (1997). *Economie als Maatschappijwetenschap.* Amsterdam: Dissertation University of Amsterdam.